PB80-223746

SIP (State Implementation Plan) Preparation Manual for NOx

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Aug 76

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC INFORMATION

PB80-223746

SIP (State Implementation Plan) Preparation Manual for NOx.

Aug 76

PERFORMER: Environmental Protection Agency, Research Triangle Park, NC. Office of Air Quality Planning and Standards.
OAQPS-1.2-048

The Clean Air Act, as amended in 1970, provided that for each national ambient air quality standard (NAAQS) promulgated by the Administrator, a State Implementation Plan (SIP) for each Air Quality Control Region (AQCR) was to be developed which was to contain emission control measures that would provide for attainment and maintenance of the SIP. It is now believed that continued growth of nitrogen oxide (NOx) emissions from mobile and stationary sources in a number of cases will make it difficult to maintain national standards in some areas where they are not presently being exceeded. Thus, additional NOx emission control measures may be necessary in some areas to assure attainment and maintenance of national standards. This SIP Preparation Manual for NOx has been prepared to provide guidance to EPA Regional Offices and State and local control agencies on the development of an approvable control strategy for nitrogen oxides.

KEYWORDS: *Nitrogen oxides, *Air pollution, *Air pollution abatement, *Guidelines, *State implementation plans, *Implementatin Air Pollution Planning program.

Available from the National Technical Information Service, Springfield, Va. 22161

PRICE CODE: PC A08/MF A01

PB80-223746

GUIDELINE SERIES

OAQPS NO. 1.2-048

SIP PREPARATION MANUAL FOR NO_x

U.S. ENVIRONMENTAL PROTECTION AGENCY

Office of Air Quality Planning and Standards

Research Triangle Park, North Carolina

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

- SIP PREPARATION MANUAL FOR NO_x -

OAQPS NO. 1.2-048

August 1976

U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Control Programs Development Division
Research Triangle Park, N. C.

INTRODUCTION

The Clean Air Act, as amended in 1970, provided that for each national ambient air quality standard (NAAQS) promulgated by the Administrator, a State Implementation Plan (SIP) for each Air Quality Control Region (AQCR) was to be developed which was to contain emission control measures that would provide for attainment and maintenance of national standards, generally within three years of the approval of the SIP. Experience has shown that not all SIP's developed by the States in early 1972 were adequate to provide for attainment and maintenance of the nitrogen dioxide (NO_2) standard by July, 1975. Further, it is now believed that continued growth of nitrogen oxide (NO_x) emissions from mobile and stationary sources in a number of cases will make it difficult to maintain national standards in some areas where they are not presently being exceeded. Thus, additional NO_x emission control measures may be necessary in some areas to assure attainment and maintenance of national standards. This SIP Preparation Manual for NO_x has been prepared to provide guidance to EPA Regional Offices and State and local control agencies on the development of an approvable control strategy for nitrogen oxides.

FORMAT

The SIP Preparation Manual for NO_x is separated into four sections. Section I provides an overview of various factors that must be considered in the development of an approvable control strategy for NO_x. Section II sets forth a fairly concise step-by-step procedure that a control strategy developer should follow in preparing an approvable control strategy. Section III provides, in question-and-answer format, additional information on recommended procedures outlined in Section II. Section IV provides a more thorough discussion of NO_x background information along with references to additional sources of information.

This manual will be revised from time to time as new information becomes available.

TABLE OF CONTENTS

Page

Section I: Overview of NO_x Control Programs 1

Section II: Summary of Procedures Required for the Development of a State Implementation Plan Control Strategy for Nitrogen Oxide 5

Section III: Questions Frequently Asked Concerning NO_x 17

(A) Control Strategy Development 17

- What is the NAAQS for NO_2? 17
- Should a SIP control strategy revision be delayed simply because no NO_2 reference measurement technique has been promulgated at this time? 17
- How large an ambient NO_2 data base is needed to develop a control strategy? 17
- Are available NO_x emission factors satisfactory for control strategy development work? 18
- What automotive emissions factors should be used to estimate the anticipated impact of the FMVCP on automotive emissions of NO_x? 18
- Can NO_x emission reductions be expected to result from Transportation Control Measures (TCM) implemented to reduce CO and/or O_3 concentration? 18
- Should TCM's be adopted solely for NO_x control? . . . 19
- Does the rollback model which is recommended for NO_x control strategy development work satisfactorily considering the different stack height of NO_x sources in an urban area? 19
- Should ambient NO_x background concentrations be considered in control strategy development work? 20

(B) Ambient Air Quality Monitoring for NO_2 21

- What is the status of the development and promulgation of a new reference technique for NO_2? 21
- What NO_2 ambient measurement techniques are satisfactory to provide ambient data to be used for SIP control strategy development work? 21
- Must a correction factor be applied to relate NO_2 data from one measurement technique to another? . . . 23
- How much ambient air quality data exists in EPA's SAROAD system? 23
- Historically, what type of ambient NO_2 air quality trends have been observed? 25

(C) NO_x Emission Data 27

- What are the major sources of NO_x in the nation? . . . 27
- What NO_x emission data are needed to develop a control strategy? 29
- How is NO_x produced during the fuel combustion process? 30
- Should the impact of stationary source fuel switches required by the Energy Supply and Environmental Coordination Act of 1974 (ESECA) be considered in the development of the NO_x control strategy? 31
- Historically, what type of NO_x emission trends have been observed? 33

Page

(D) NO_x Control Technology 35

- What is considered to be reasonably available control technology for stationary sources of NO_x? . . 35
- Can significant NO_x emission reductions be expected to result from combustion modifications to existing utility type boilers? 35
- What is considered to be achievable NO_x control technology for stationary sources? 37
- If achievable NO_x emission limitations in conjunction with the FMVCP are not adequate to provide for attainment of the NAAQS for NO_2, what type of additional control measures should be adopted? 38
- Will the application of combustion modifications to reduce NO_x emissions from utility type boilers effect emissions of other criteria pollutants? . . 39

(E) Miscellaneous 41

- How is NO converted to NO_2 in the atmosphere? . . 41
- Does HC control have any effect on ambient NO_2 concentrations? 41
- Are any existing stationary sources required to continuously monitor NO_x emissions? If so, which sources? 41
- Are new stationary sources of NO_x required to monitor emissions? 42

Section IV: Support Information . . . .

History of NO_x Control Under the Clean Air Act . . . Section A

Current Status of Ambient NO_2 Measurement Methods . . Section B

NO_2 Formation Processes and Control Strategy Modeling . . . . Section C

Control of Oxide of Nitrogen for Stationary Sources Section D

Motor Vehicles . . . . Section E

Transportation Control Plans . . . . Section F

Field Observations . . . . Section G

ABBREVIATIONS AND SYMBOLS

Act - the Clean Air Act as amended
AP-42 - *Compilation of Air Pollutant Emission Factors*, EPA
APTIC - Air Pollution Technical Information Center
AQCR - Air Quality Control Region
CO - Carbon Monoxide
EGR - Exhaust Gas recirculation
EMSL - Environmental Monitoring and Support Laboratory, EPA
ESECA - Energy Supply and Environmental Coordination Act
FGR - Flue Gas Recirculation
FGT - Flue Gas Treatment
FMVCP - Federal Motor Vehicle Control Program
HDVD - Heavy Duty Vehicles-Diesel Powered
HDVG - Heady Duty Vehicles-Gasoline Powered
I/M - Inspection/Maintenance
LDT - Light Duty Trucks
LDV - Light Duty Vehicles
LEA - Low Excess Air
NAAQS - National Ambient Air Quality Standards
NMHC - Non-methane Hydrocarbons
NO - Nitric Oxide
NO_2 - Nitrogen Dioxide
NO_x - Nitrogen Oxides ($NO + NO_2$)
NSPS - New Source Performance Standards
O_x - Oxidants
O_2 - Oxygen
O_3 - Ozone
OSC - Off-stoichometric Combustion
RACT - Reasonably Available Control Technology
SIP - State Implementation Plan
SAROAD - Storage and Retrieval of Aerometric Data
TCM - Transportation Control Measure
TCP - Transportation Control Plan
TEA - Triethanolamine
TGS - Triethanolamine-guaiacol-sulfite
VMT - Vehicle Miles Traveled
VSAD - Vacuum Spark Advance Disconnect

SECTION I

OVERVIEW OF NO_x CONTROL PROGRAMS

The following statements summarize the current knowledge concerning the nature and extent of the NO_2 problem and the technical information available to assist in the development of approvable NO_x control measures.

1. The primary and secondary National Ambient Air Quality Standard for NO_2 is 100 $\mu g/m^3$ annual arithmetic average. The need for an additional short-term standard has been reviewed. Based on available information, it is thought unlikely that a short-term NO_2 standard will be promulgated in the immediate future. Therefore SIP revisions for NO_2 should address the present annual standard and do not need to consider short-term NO_2 concentrations.

2. Although limited, valid NO_2 data indicate that only a few areas of the country have ambient NO_2 concentrations in excess of the NAAQS for NO_2. On an overall national basis, the NO_2 problem appears much less severe and pervasive than the total suspended particulate (TSP) or oxidant (Ox) problem.

3. Difficulties with ambient NO_2 monitoring techniques have been principally resolved in the following manner:

(a) The original Federal Reference Method for NO_2, the Jacobs-Hochheiser 24-hr. bubbler technique, has been revoked and should no longer be used.

(b) The continuous chemiluminescence measurement principle and associated calibration procedure was proposed in the Federal Register on March 17, 1976, as the basis for the new Federal Reference Method for NO_2.

(c) The (1) TGS (triethanolamine-guiacol-sulfite) and (2) sodium arsenite orifice 24-hr. bubbler methods are also satisfactory for NO_2 ambient monitoring and will be tested for designation as equivalent methods.

(d) The (1) continuous colorimetric (Saltzman) analyzer, (2) TEA (triethanolamine) and (3) sodium arsenite frit 24-hour bubbler methods are thought at this time to be capable of producing accurate air quality data and data collected by these methods can be used for control strategy development work. However, the likelihood of any of these methods producing valid data over a year's time is not as great as for the previously mentioned methods.

(e) Data from the (1) Jacobs-Hochheiser or (2) Saltzman 24-hr. bubbler techniques should not be used.

4. With a few exceptions, the typical annual NO_2 problem, where it does exist, is in an urban area where observed NO_2 concentrations are either slightly above or below the NAAQS. Such conditions generally represent a potential problem of maintenance of the NAAQS rather than attainment of such standards.

5. Stationary source control measures will become increasingly important as mobile source controls become more fully implemented. Studies have been conducted that predict future violations of the NO_2 standard will occur in some areas regardless of automotive NO_x emission standards because of growth of stationary source emissions.

6. On a national basis, stationary sources and mobile sources contribute 60% and 40% of the NO_x emissions, respectively. In both emission categories, the vast majority of NO_x emissions is produced by fuel combustion (fossil fuel-fired power plants, industrial boilers, commercial/residential space heating units, gasoline-powered automobiles, diesel-powered trucks, aircraft, etc.).

7. At this time the rollback model (basic or modified) is the recommended source/receptor relationship for NO_x control strategy review and/or development work.

8. Although the magnitude of the NO_2 problem and required reduction in NO_x emissions is not large, in general NO_x control techniques are limited (not reasonably available for all source categories).

9. The greatest activity in developing NO_x control technology has been with utility type boilers and nitric acid plants. NO_x control techniques are more advanced for gas and/or oil-fired boilers than coal-fired boilers. Reasonably available control measures for these source categories include:

(a) For utility type boilers (greater than 250 x 10^6 BTU/hr heat input) - Combustion modifications

(1) Lower excess air

(2) Staged combustion

(3) Burner modification or replacement

(4) Flue gas recirculation (for gas or oil-fired boilers with recirculation provisions)

(b) Nitric Acid Plants - Catalytic Decomposition

10. NO_x control techniques which are not widely applied at the present time or which are not presently available but which are expected to be available (i.e., achievable) in the next few years include the following:

(a) Utility type boilers (greater than 250 x 10^6 BTU/hr heat input) - Combustion Modification

(1) Water or steam injection (oil or gas-fired)

(2) Preheat reduction

(3) Derating can be considered as a potential NO_x control measure but it should be reviewed on a case-by-case basis considering its effectiveness and feasibility.

(4) Firebox enlargement.

(b) Small and medium-size Commercial/Industrial boilers (less than 250 x 10^6 BTU/hr heat input) - Burner modification or replacement.

(c) Gas turbines

(1) Water and steam injection

(2) New combustor designs

(d) Stationary internal combustion engines - exhaust gas recirculation, turbo-charging with after cooling

(e) Chemical process (ammonium nitrate, fertilizer, explosive production, etc.) - caustic scrubbing, NO_x incineration in reducing atmosphere, etc.

(f) Industrial combustion processes (metallurgical, kilns, glass production) - combustion modification

SECTION II

SUMMARY OF PROCEDURES REQUIRED FOR THE DEVELOPMENT OF A STATE IMPLEMENTATION PLAN CONTROL STRATEGY FOR NITROGEN OXIDES

The following section discusses the nine major steps required in the development of a SIP control strategy revision for NO_2. The amount of work involved in each step will vary from area to area depending on available data, magnitude of NO_2 problem, types of NO_x sources, etc. The nine steps can be summarized as follows:

STEP 1 - Determine if available NO_2 data indicate the NAAQS for NO_2 is being exceeded or has the potential of being exceeded in the near future.

STEP 2 - Determine if the available ambient air quality data is valid.

STEP 3 - Determine the maximum representative NO_2 concentration.

STEP 4 - Determine the area to be addressed by the NO_x control strategy.

STEP 5 - Determine the sources of NO_x.

STEP 6 - Determine the growth potential for the study area.

STEP 7 - Using the proportional model, determine the NO_x emission reduction requirements.

STEP 8 - Determine NO_x reduction expected to result from existing NO_x regulation (FMVCP, NSPS, etc.).

STEP 9 - Considering RACT and achievable control technology, develop a control strategy to attain and maintain NAAQS for NO_2. If needed, other control measures should also be incorporated into the NO_x control strategy.

Listed below and discussed in more detail are the nine principal steps for developing a State Implementation Plan Control Strategy for NO_x.

STEP 1: Review available NO_2 air quality data to determine if sufficient data are available to provide evidence that the national standards are not being attained or will not be maintained. Are sufficient data available to calculate valid annual average concentrations within the study area? Valid data from at least one site with one year of data should be available, however, 3 years or more of data are preferable. Data should be available for areas of expected maximum concentrations; however, lack of such data should not preclude the development of a control strategy if available data indicate valid violations of national standards. (Note: Predictive models do not exist to estimate ambient NO_2 air quality levels.)

STEP 2: If data exist to indicate a potential attainment or maintenance problem, review the ambient air quality data to determine its validity and representativeness.

(a) Review the location of the NO_2 monitors. Are they properly located in accordance with siting criteria?* Are sites biased toward local conditions such that they do not represent areawide problems? (Note: Local problems should not be ignored, however, the objective of the review is to determine the sources and geographical area to be considered in the control strategy analysis.)

---

*OAQPS presently plans to distribute a supplement to OAQPS Guideline 1.2-012 (Guidance for Air Quality Monitoring Network Design and Instrument Siting) by late 1976 which will update existing NO_2 monitoring guidelines.

(b) Determine if a satisfactory measurement procedure was used to collect NO_2 data being analyzed. The following measurement procedures are acceptable as indicated. If data are collected by an unacceptable measurement technique, data should not be used.

Measurement Method (Method Code)	Comment
Instrumental	
(11) Modified Saltzman Colorimetric	Data can be used with caution *
(12) Saltzman Colorimetric	Data can be used with caution
(13) Coulometric	Data can be used with caution
(14) Chemiluminescence	Proposed Federal Reference Method Data can be used
Bubblers	
(71, 81, 91) Jacobs-Hochheiser - Data must not be used	
(72, 82, 92) Saltzman Bubbler - Data must not be used	
(84) Sodium Arsenite Orifice	Candidate Federal Equivalent Method Data can be used
(94) Sodim Arsenite - Frit	Data can be used with caution
(95) TEA	Data can be used with caution
(96) TGS	Candidate Federal Equivalent Method Data can be used

*User should be aware of the problems associated with the method and be assured that proper procedures were used in collecting data.

(c) Analyze the available NO_2 air quality data to assure its validity and reliability.

(1) Determine if the data were collected by monitors that are properly operated, maintained and that adequate quality control procedures were utilized to assure validity of data.

(2) Review specific data for determination of abnormal values. Obtain frequency distributions of NO_2 data. Air quality statistics such as geometric mean, arithmetic mean, standard deviation, and frequency percentiles may suggest abnormal values. For example:

- Both the standard deviation and the magnitude of the difference between the geometric and the arithmetic mean are more sensitive to a few extremely high values than to many moderately high values.

- Inspection of the higher percentile values also will identify abnormal high values.

- Generally the standard deviation should not vary much from year to year.

(3) The collecting agency should attempt to validate any suspicious data and to generally acknowledge that all the data have been reviewed and are considered valid and useable for control strategy development work. Where necessary, this review should include:

A. Review of strip charts and laboratory reports, and field log books for notations concerning operations and maintenance activities.

B. Review basic data to assure temporal balance of air quality data (e.g., a missing quarter of air quality data).

C. Have any changes been made in sampling methodology, maintenance procedures, calibration procedures or quality control practices?

(4) If abnormally high values have been measured and are considered suspect, it may be useful to review operating parameters for other

instruments at the same monitoring site to determine whether electrical problems or heating/air conditioning problems may have caused abnormal values.

(5) Review data from nearby monitoring sites and compare the concentrations measured by the other instruments at those sites with the concentrations measured by sampling instruments at the site in question.

(d) To determine if NO_2 air quality concentrations are representative, review the NO_2 air quality trend at each site for the area being studied. To the degree possible, determine if unusual events may have caused high NO_2 concentrations (e.g., industrial accident at nitric acid plant or severe meteorological conditions that may cause unusually high NO_2 concentrations.

(1) Review the NO_2 trend at each site to identify fluctuation in NO_2 levels.

(2) Review parameters that would help explain trend.

- Review NO_x emissions inventory, growth projections, construction permits, and compliance information to determine if any significant changes (increases or decreases) in regional NO_x emissions have taken place. NOTE: The purpose of Step 2 is to insure that the data which will be used as the basis of a control strategy are valid, or can reasonably be assumed to be valid. If it is believed that the data are questionable and factors exist that could reasonably challenge the data validity, then such data should not be used as the basis of a control strategy. If on the other hand, all reasonable measures have been followed in the collection of the data, and unless the validation efforts prove the data to be invalid, then such data should be assumed valid and usable.

STEP 3: Determine the maximum measured ambient level that best represents ambient air quality levels in the area. Determine if such air quality data are of sufficient magnitude that a further analysis of existing and anticipated emissions data should be conducted to determine if national standards will be attained and maintained. This analysis should be conducted if ambient air quality levels are equal to or exceed national standards. Also, in those areas where growth of new emission sources is expected, the analysis should be conducted even if national standards are being attained on a marginal basis.

STEP 4: Determine the geographic area to be considered in the analysis. From available data, determine the geographic area where national standards are violated or are anticipated to be violated due to growth of emission sources. It is not necessary to use an entire AQCR or county. The area does not have to be a political entity. Some consideration should be given to political boundaries, however, since the regulations which implement the control strategy will ultimately be enforced by local governments. Although some advantages accrue to the use of a commonly identified geographical area, as long as the area is clearly defined, it is appropriate for development of a control strategy. The area of concern should be "future-oriented," in that strong consideration should be given to growth of emission sources.

More specifically, data indicate that areas slightly downwind from the major urban center but within the urban area are the expected areas of maximum annual NO_2 levels. Ambient NO_2 levels 20 miles or more distant from the urban fringe are affected to a very minor degree by urban NO_x emissions. Similarly, sources generally located more than 20 miles from the urban areas will minimally impact air quality within the urban area. It is recommended therefore that the geographic area to be considered for NO_x control strategy for attainment purposes include the urban area and the adjacent counties. Of course from a maintenance point of view, growth of sources throughout some area larger than the current urbanized area may need to be considered. In such cases, areas of expected growth should be considered in defining the geographical area to be addressed by the NO_x control strategy.

STEP 5: Determine the sources of NO_x emissions in the area and calculate the emissions from each source. Data are needed for two purposes:

(a) To assess where the ambient NO_2 problem originates.

(b) To determine the emissions reduction impact of various possible control regulations on source emissions.

Most emission inventories are adequate to provide for the assessment of the sources of NO_x emissions in the area, however, for certain emission categories such as fuel combustion sources, available data may not be adequate for possible control strategy development. Specifically, detailed information on fossil fuel-fired steam generators (e.g., excess air usage, boiler configuration, number of burners, fuel specifications, etc.) is needed to determine a boiler's emission reduction potential.

Similarly, detailed information for mobile sources such as vehicle mix ratio (LDV, LDT, HDVG & LDVD) and age distribution for the area under study may be necessary to determine the impact of the FMVCP and/or various transportation control measures. Since this type of information is not commonly associated with existing emission inventories, it may be necessary to collect some additional data.

More specific procedures for compiling an emission inventory are contained within Guide for Compiling a Comprehensive Emission Inventory

(EPA/APTD 1135, March 1973). Further, specific information, as well as emission factors that can be used to calculate NO_x emissions from various mobile and stationary sources, are contained in Compilation of Air Pollutant Emission Factors (AP-42).

STEP 6: Determine the expected increase of NO_x emissions due to growth (generally over the next 20 year period). Growth is an inherent part of air pollution control; and consideration of growth is thus paramount in the development of a control strategy. The adjustment of the emissions inventory to account for growth is essentially a projection of the levels of economic and demographic activity and its impact on air quality in the area of concern.

The information needed to develop growth factors originates from Federal agencies, from State and local governments, and from private business interests. Fairly specific information should be obtained from State and local planning agencies if possible. If unavailable, the growth projections of the Office of Business Economics (OBE), presently the Bureau of Economic Analysis of the U. S. Department of Agriculture can be used. These projections, called "OBERS projections" are available at the EPA Regional Offices. Since most NO_x is produced from combustion processes, the development of growth factors should be centered on these source categories (power plants, industrial boilers, commercial/residential space heating, mobile sources, etc.).

Numerous guidelines have been prepared by EPA with regard to projecting growth in emissions and allocating such growth. These techniques are too detailed to summarize here. The reader is referred to the following documents for additional information:

Air Quality Maintenance Guidelines:

Vol. 3, Plan Preparation (EPA-450/4-74-003)

Vol. 7, Projecting County Emissions (EPA-450/4-70-008)

Vol. 13, Allocating Projected Emisssions to Sub-County AQMA (EPA-450/4-74-004)

STEP 7: Using the proportional model, determine the degree of control needed to attain and maintain the NAAQS. The modified rollback is also recommended for NO_x control strategy development work.

The Modified Rollback can be expressed as:

$$\left(\frac{X_2 - B}{X_1 - B}\right) \sum_{i = 1}^{N} (Q_i) \text{ base year} = \sum_{i = 1}^{N} Q_iG_i)_{\text{future}}$$

where X_1 = SIP design value (representative maximum annual average NO_2 concentration in base year)

X_2 = NAAQS for NO_2 (100 $\mu g/m^3$)

B = annual NO_2 background concentration (8 $\mu g/m^3$)

Q_i = annual NO_x emission rate per source category

G_i = a growth factor, e.g., the ratio of NO_2 emissions at attainment data or during maintenance period to NO_2 emissions in the base year per source category

N = the number of source categories

i = a particular source category, e.g., light-duty vehicles, stationary sources, etc.

In cases where the area-wide NO_x emissions result from a variety of source types with differing emissions and growth rates and where various control strategies are to be investigated, the modified rollback model will allow the situation to be studied in more detail than the rollback procedure.

To apply this technique, the left side of the equation is evaluated with available data to determine an allowable NO_x emission rate. The right side of the equation is then evaluated for various control strategies until a strategy which demonstrates attainment and assures maintenance is developed.

STEP 8: Determine how large an NO_x emission reduction can be achieved by full implementation of existing adopted control regulations.

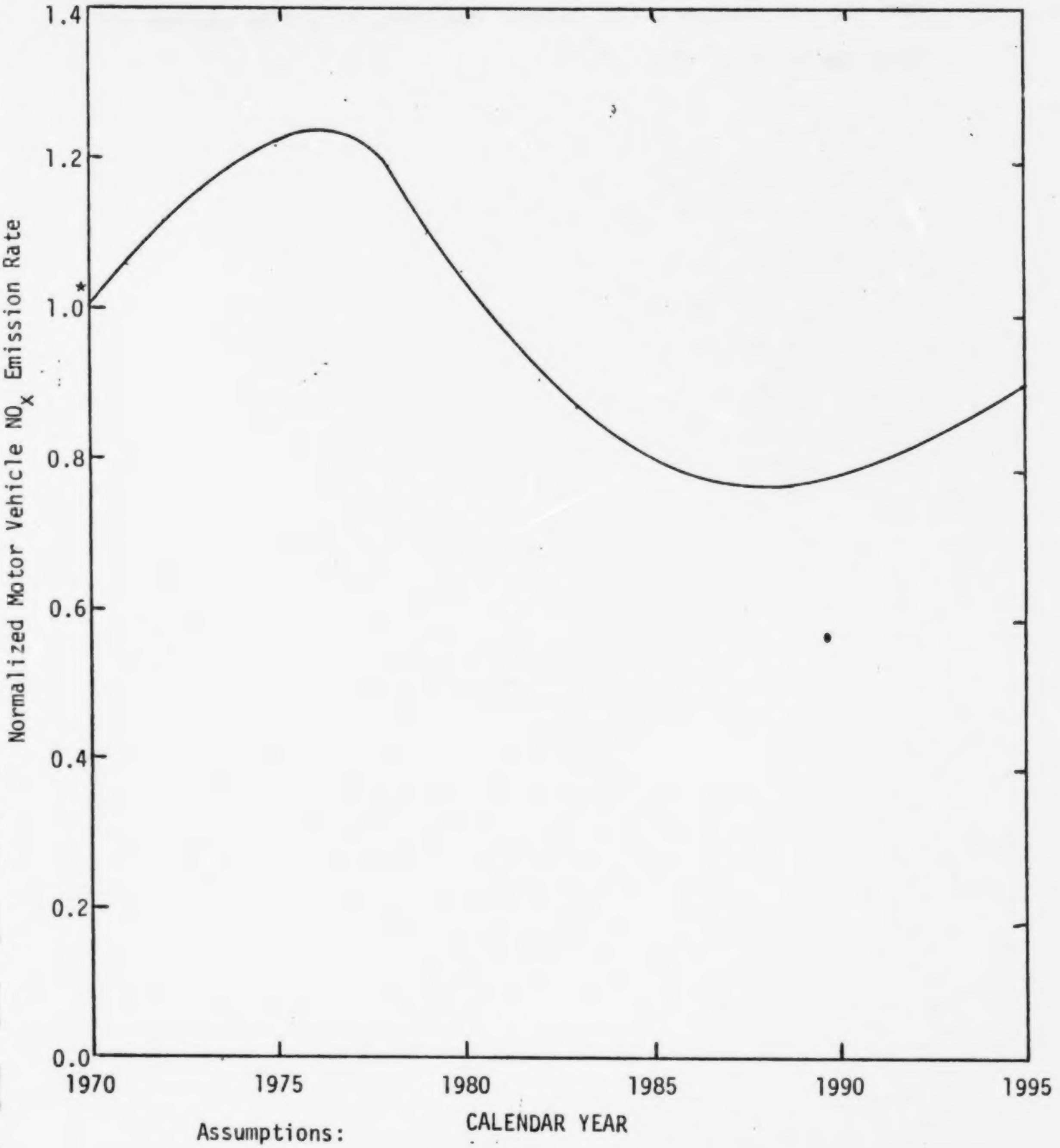
(a) Consider the impact of the FMVCP on NO_x emissions. Figure II-1 presents a plot of projected national NO_x emissions from motor vehicles. Additionally, AP-42 can be used to develop city specific curves if needed.

(b) Consider the impact on NO_x emissions (both increases and decreases) that may result from (1) compliance with existing control regulations, (2) ESECA or other fuel switches, (3) TCM or I/M program for CO or Ox.

STEP 9: If additional controls are needed, consider the application of (a) reasonably available control technology and if needed (b) achievable control measures (technology forcing). The term "achievable" is intended to require reasonably "technology forcing" control measures if necessary, rather than simply "off-the-shelf technology." SIP revisions submitted by July 1977 shall require all achievable control technology for stationary sources (as needed) to provide for attainment of the national standard.

FIGURE II-1

NORMALIZED MOTOR VEHICLE EMISSIONS RATE



Assumptions:

1. National average automobile and truck age distribution
2. Low altitude, standard conditions
3. 3% Compounded (annual) growth rate
4. National average vehicle mix (LDV 80.4%; LDT 11.8%; HDG 4.6%; HDD 3.2%)
5. 1970 composite emission factor 4.6 g/mi

Additionally, if needed, "other" control measures, including land use and transportation control measures, should be adopted and submitted by July 1978.

SECTION III - QUESTIONS FREQUENTLY ASKED CONCERNING NO_x

- Control Strategy Development -

QUESTION - What is the NAAQS for NO_2?

ANSWER - The primary and secondary NAAQS for NO_2 is 100 $\mu g/m^3$ annual arithmetic mean measured as NO_2. Recently a review was performed to determine the need for an additional short-term NO_2 NAAQS. Based on available information, it is thought unlikely that a new short-term standard will be developed in the immediate future. SIP revisions should only address the present annual NAAQS for NO_2.

QUESTION - Should a SIP control strategy revision be delayed simply because no NO_2 reference measurement technique has been promulgated at this time?

ANSWER - No. Detailed studies of ambient NO_2 measurement techniques have been completed which assess each measurement technique. The results of these studies indicate that valid data can be obtained using various methods. Control strategy development work should be initiated using representative NO_2 air quality data.

QUESTION - How large an ambient NO_2 data base is needed to develop a control strategy?

ANSWER - As a minimum, valid annual air quality data from at least one site is required. Although the seasonal variability of NO_2 is minor in most areas, NO_2 air quality data should be available for all four quarters of the year of interest to accurately determine the annual arithmetic mean. Additionally, 2 or 3 years of valid data from a monitoring site are preferred to a single year's data. Further, data from more than one site is preferable, including a site at the area of probable maximum concentration.

ADDITIONAL INFORMATION - See Section G - Field Observations

QUESTION - Are available NO_x emission factors satisfactory for control strategy review or development work?

ANSWER - Generally, yes. NO_x emission factors are satisfactory for a regional assessment of total NO_x emissions but may be less accurate for estimating some individual source emissions. For example, NO_x emission factors for coal combustion (and fuel oil in some cases) represent average emissions for typical conditions and at this time do not directly allow for consideration of the variable nitrogen content of coal. In many cases 50% but in extreme cases up to 80% of the NO_x emitted from coal combustion is associated with the nitrogen in the fuel. The nitrogen content of U. S. coals can vary from 1.0% to 2.0%. It is recommended that emission factors contained in AP-42 and its associated update supplements be used for NO_x control strategy development work.

QUESTION - What automotive emission factors should be used to estimate the anticipated impact of the FMVCP on automotive emissions of NO_x?

ANSWER - The automotive emissions regulations (FMVCP) associated with ESECA are in effect. Congress is currently considering Act amendments and may revise them. Until the amendments are completed, the current exhaust emission limitation associated with the FMVCP should be used for SIP control strategy work. Additionally, procedures and data described in AP-42 can be used to develop city specific automotive emission factors.

QUESTION - Can NO_x emission reductions be expected to result from Transportation Control Measures (TCM) implemented to reduce CO and/or O_3 concentration?

ANSWER - Some NO_x emission reductions can be realized from some of the CO-O_x TCM's but the measures used in the CO-O_x TCM's must be carefully analyzed to assess the amount of NO_x control achieved. For example, reductions in vehicle miles travelled (VMT), retrofit of exhaust gas recirculation (EGR) or vacuum spark advance disconnect (VSAD) can directly reduce NO_x emissions. However, inspection/maintenance programs (I/M) for CO-O_x TCM's may have little effect on NO_x emissions.

ADDITIONAL INFORMATION - See Section F - Transportation Control Measures.

QUESTION - Should TCM's be adopted solely for NO_x control?

ANSWER - Reductions in NO_x emission from CO and/or O_x TCM's should be determined and incorporated into the NO_x control strategy as applicable. At this time it is thought unlikely that NO_x reduction would become a key determinant of TCM policy, however in certain areas, such measures in conjunction with stationary source control may be required to provide for attainment of NO_2 standards.

QUESTION - Does the rollback model which is recommended for NO_x control strategy development work satisfactorily consider the different stack height of NO_x sources in an urban area?

ANSWER - Yes, generally 1 to 3 hours is required for NO to NO_2 conversion, thus NO emitted from low and high level sources in the problem area is constantly diffusing and mixing while NO_2 is forming and results in NO_x source contributions being nominally related to stack height. Therefore in most cases the proportional model will satisfactorily describe the urban NO_x emission - NO_2 air quality relationship on an annual basis and is the best readily available model for NO_x control strategy development work at this time.

ADDITIONAL INFORMATION - 1. See Section C - NO_x Formation Processes and Control Strategy Modeling.

QUESTION - Should ambient NO_2 background concentrations be considered in control strategy development work?

ANSWER - Yes. An annual average NO_2 background concentration of 8 ug/m^3 should be assumed for control strategy development if other background concentration data are not available. Natural background concentrations are a result of natural bacterial and plant actions.

- Ambient Air Quality Monitoring for NO_2 -

QUESTION - What is the status of the development and promulgation of a new reference technique for NO_2?

ANSWER - The Environmental Monitoring and Support Laboratory, EMSL, has completed its study of ambient NO_x measurement methods. The chemiluminescence measurement principal and associated calibration procedure was proposed to the public in the Federal Register on March 17, 1976, as the basis for the new NO_2 reference method. The schedule for other actions is listed below:

Date	Action
3/76	Propose continuous chemiluminescence measurement principle and calibration procedure (40 CFR Part 50).
3/76	Propose reference and equivalency requirements (40 CFR Part 53).
10/76	Promulgate measurement principle and calibration procedure: promulgate reference and equivalency requirements.
2/77	Designate reference methods (40 CFR Part 53) and identification of acceptable commercial instruments.
3/77	Designate equivalent methods (40 CFR Part 53). (Arsenite and TGS are expected to be designated as equivalent methods.

ADDITIONAL INFORMATION - Current Status of Ambient NO_2 Measurement Methods.

QUESTION - What NO_2 ambient measurement techniques are satisfactory to provide ambient data to be used for SIP control strategy development work?

ANSWER - Three ambient NO_2 monitoring methods are reliable and capable of producing valid NO_2 air quality data on an annual basis for control strategy development work. The methods are (1) the continuous chemiluminescence measurement principle and associated calibration procedure,

(2) TGS (triethanolamine-guiacol-sulfite) and (3) sodium arsenite orifice 24-hr. bubbler methods. The continuous chemiluminescence measurement principal and associated calibration procedure has been proposed in the Federal Register on March 17, 1976, as the basis for the Federal Reference Method for NO_2. The TGS and sodium arsenite orifice 24-hr. bubbler methods will be tested for designation as equivalent methods.

At this time it is also thought that three other methods when properly used can also produce valid air quality data for control strategy development work. However, the likelihood of any of these methods producing valid data for an annual average is not as great as for the previously mentioned methods. These less reliable methods are the (1) continuous colorimetric (Saltzman) analyzer, (2) TEA (triethanolamine) and (3) sodium arsenite frit 24-hr. bubbler methods.

ADDITIONAL INFORMATION - See Section A - History of NO_x Control Under the Clean Air Act. Section B - Current Status of Ambient NO_2 Monitoring Methods. The following reports from EPA's Environmental Monitoring Series are also available from the Air Pollution Technical Information Center (APTIC):

1. EPA-650/4-74-019-a: Collaborative Testing of Methods for Measurement of NO_2 in Ambient Air, Volume 1 - Report of Testing.

2. EPA-650/4-74-031: Evaluation of Triethanolamine Procedure for Determination of Nitrogen Dioxide in Ambient Air.

3. EPA-650/4-74-046: Collaborative Test of the TGS-ANSA Method for Measurement of Nitrogen Dioxide in Ambient Air.

4. EPA-650/A-75-011: Collaborative Test of the Continuous Colormetric Method for Measurement of Nitrogen Dioxide in Ambient Air.

5. EPA-650/4-74-047: An Evaluation of TGS-ANSA Procedure for Determination of Nitrogen Dioxide in Ambient Air.

6. EPA-650/4-74-048: An Evaluation of Arsenite Procedure for Determination of Nitrogen Dioxide in Ambient Air.

7. EPA-650/4-75-019: Evaluation of Effects of NO, CO_2, and Sampling Flow Rate on Arsenite Procedure for Measurement of NO_2 in Ambient Air.

8. EPA-650/4-75-021: Evaluation of Gas Phase Titration Technique as Used for Calibration of Nitrogen Dioxide.

9. EPA-650/4-75-022: Evaluation of Continuous Colormetric Method for Measurement of Nitrogen Dioxide in Ambient Air.

10. EPA-650/4-75-023: Comparison of Methods for Determination of Nitrogen Dioxide in Ambient Air.

QUESTION - Must a correction factor be applied to relate NO_2 data from one measurement technique to another?

ANSWER - No correction factor is required to relate NO_2 data from different measurement techniques assuming they have been operated properly. Each acceptable monitoring technique provides reliable information with respect to ambient NO_2 levels.

QUESTION - How much ambient air quality data exist in EPA's SAROAD system?

ANSWER - Listed in Table III-1 are summary statistics of the 1974 NO_2 data contained in SAROAD as reported in the 1974 Monitoring and Air Quality Trends Report. More current data are generally available from

TABLE III-1

NO_2 AMBIENT AIR QUALITY MONITORS IN USE-NATIONAL TOTAL

Measurement Method (Method Code)	Number of[1] Monitors Reporting	Number of[1] AQCR's Reporting
Instrumental		
(11) Modified Saltzman Colorimetric	131	39
(12) Saltzman Colorimetric	10	5
(13) Coulometric	8	8
(14) Chemiluminescence	72	35
TOTAL	221	87
Bubblers		
(84& 94) Sodium Arsenite (Orifice & Frit)	1196	158
(95) TEA	0	0
(96) TGS	5	1
TOTAL	1201	159
GRAND TOTAL	1422[2]	168 Total No. of AQCR's Reporting

[1] Based on 1974 Trends Report (updated) and does not include Jacobs-Hocheiser or Saltzman Bubbler data.

[2] Note that only 610 sites (106 AQCR's) of the 1422 sites (168 AQCR's reporting) have reported enough ambient NO_2 air quality data to calculate an annual mean.

SAROAD and State agencies. The Regional Offices, State and local air pollution control agencies are encouraged to submit any additional NO_2 air quality data obtained to SAROAD so that it can be stored for future reference.

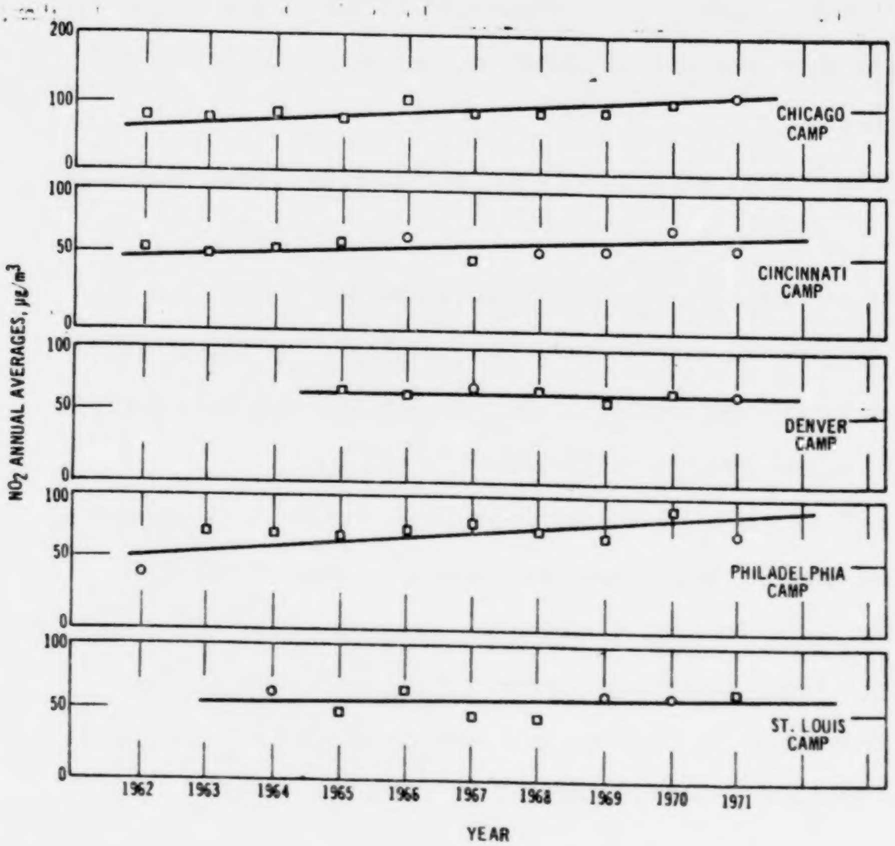
QUESTION - Historically, what type of NO_2 air quality trends have been observed?

ANSWER - Trends in ambient NO_2 concentrations at CAMP sites have been analyzed for Chicago, Cincinnati, and Philadelphia. The NO_2 graphs and regression lines (See Figure III-1) indicate, for the most part, an increase in annual average concentration with time.

Further, it is now believed that continued growth of NO_x emissions from stationary sources in a number of cases will make it difficult to maintain the NAAQS for NO_2 in some areas where they are not presently being exceeded. Thus, additional control of NO_x emissions may be necessary in some areas to restrict the upward trend of NO_x emissions to assure the attainment and maintenance of the NAAQS for NO_2.

FIGURE III-7

NO_2 Air Quality Trends at CAMP Sites*



Station	Annual Average NO_2 Concentration ($\mu g/m^3$)		Percent Change
	1962-66	1967-71	
Chicago	86.1	101.2	+18
Cincinnati	62.0	60.1	- 3
Denver	66.0	67.9	+ 3
Philadelphia	67.7	77.6	+15
St. Louis	58.5	54.2	- 7
CAMP average	68.1	72.2	+ 6

□ Valid annual average

○ Indicates average based on incomplete data

*Measurements made with Modified Saltzman (colormetric) Method, the National Air Monitoring Program: Air Quality and Emission Trends: Annual Report: Volume I: EPA-450/1-73-001-a.

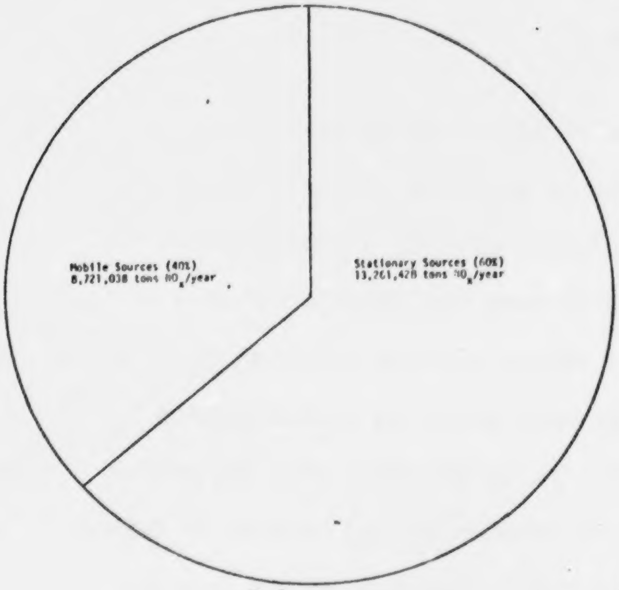
- NO_x EMISSION DATA -

QUESTION - What are the major sources of NO_x in the nation?

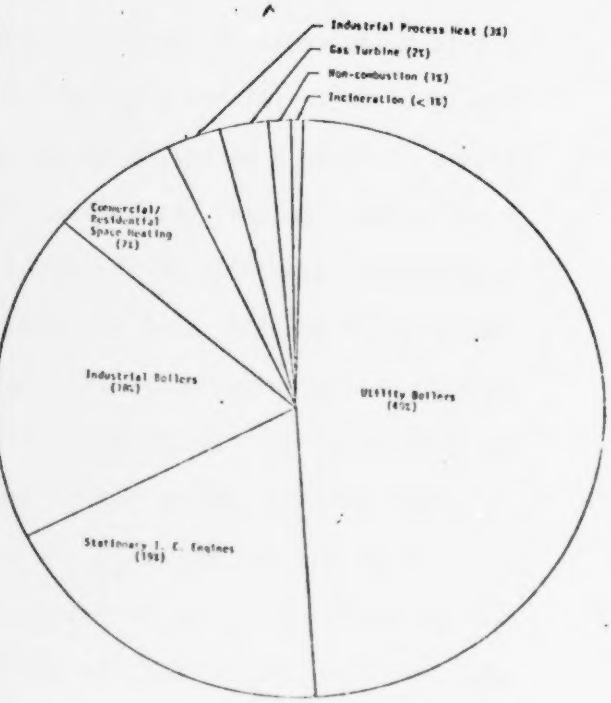
ANSWER - Nitrogen oxides (NO_x) are formed by nature and as a result of man's activities. Both sources principally emit NO_x in the form of nitric oxide (NO). Although the natural emissions which occur as a result of bacterial and plant actions exceed man-made emissions by a factor of 10 on a worldwide basis, man-made emissions predominate in urban areas. Natural emissions of NO_x are considerable when the entire geographical land area of the nation is considered, but because of their low emission density (tons NO_x/square mile), they only result in a NO_2 background concentration in the order of 8 ug/m^3. Man-made NO_x emissions in 1972 amounted to 24 million tons within the United States.

On a national basis, 60% of the man-made NO_x is generated by stationary sources and the remaining 40% by mobile sources (see Figure III-2), but the distribution can vary for specific AQCR's. For example, based upon emission data in NEDS the stationary/mobile source ratio is 76% - 24% for the St. Louis AQCR and only 43% - 57% for the Denver AQCR.

Most NO_x stationary source emissions are generated by the combustion of fuel. On a national basis, utility and industrial boilers emit 67% (49% utility and 18% industrial) of the stationary source NO_x emissions. Other sources of NO_x include stationary internal combustion engines (principally used for natural gas transmission pipeline pumping stations located in nonurban areas, 19%) and commercial/residential space heating (7%). Non-combustion NO_x sources which include nitric acid production, TNT production, etc., contribute only 7% of the national NO_x emissions.



STATIONARY - MOBILE SOURCES



STATIONARY SOURCES

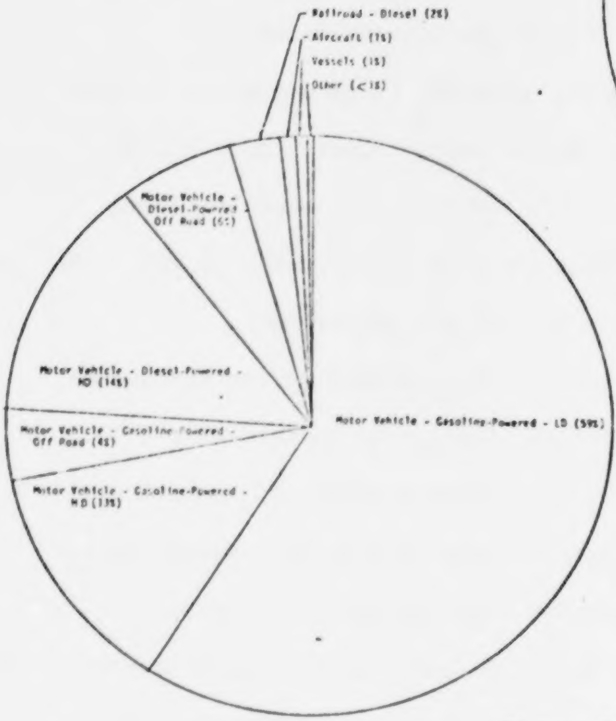


Figure III- 2

MOBILE SOURCES

NATIONAL DISTRIBUTION OF NO_x EMISSION SOURCES (1972)

Reproduced from
best available copy.

On a national basis, 76% of the mobile source NO_x emissions are generated by gasoline-powered motor vehicles (light duty - 59%, heavy duty - 13%, and off-road 4%). Additionally, diesel-powered motor vehicles contribute another 20% (heavy duty - 14% and off-road - 6%) of the nation's NO_x emissions. The remaining 4% of the national emissions are contributed by railroad, aircraft, vessels, etc. Because diesel-powered trucks are not commonly used in urban areas, gasoline-powered motor vehicles are the major urban mobile source of NO_x emissions.

QUESTION - What NO_x emission data are needed to develop a control strategy?

ANSWER - On a national basis, stationary sources contribute approximately 60% and mobile sources contribute about 40% of the total NO_x emissions (principally as NO). Thus an emission inventory for the problem area should include both categories of sources. In order to access the mobile source emission rates, data should be obtained on mobile source population by category, expected growth rates, age distribution, information on vehicle miles traveled (VMT) and fuel consumption information. Additional information may be required if mobile source controls (i.e., TCM* for carbon monoxide (CO) or oxidants O_x)) in addition to the Federal Motor Vehicle Control Program (FMVCP) are being evaluated.

For stationary sources, information on the location of large point sources and emission density of area sources is required to determine their impact on ambient NO_2 concentration. Although some processes such as nitric acid production emit enough NO_2 at one plant to be a point source, most NO_x point sources will probably be large industrial boilers or power plants. Specified data on each large industrial or utility boiler will be required if the control strategy is to address these sources. Specific data should include information on the type of fuel (specifications), firing configuration, excess air controls, number of burners, burner arrangement, availability of new low NO_x producing replacement burners, secondary air ports, etc. In some cases, such as coal-fired boilers, individual sources may have to be studied to determine NO_x control potential. The emission inventory should accurately describe NO_x emissions for the year of record and identify any scheduled increases or decreases in emissions.

---

*TCM - Transportation Control Measures

Both the NO_x emission inventory and ambient NO_2 data base used for control strategy development work should be for the same year of record. If the current NO_x emission inventory is deficient and an update is required, it may be possible to efficiently and accurately develop the inventory by principally addressing the major emission sources in the study area.

ADDITIONAL INFORMATION - See Section D - Control of NO_x for Stationary Sources.

QUESTION - How is NO_x produced during the fuel combustion process?

ANSWER - As previously indicated, the principal stationary and mobile sources of NO_x emissions are fuel combustion processes (utility boilers, industrial boilers, motor vehicles, etc.). These processes generate NO by two formation mechanisms. The principal formation method is the high temperature oxidation of the nitrogen in the combustion air supply to produce NO. Thermal NO is formed in all combustion processes, but predominates for cleaner fuels (low nitrogen content fuels) such as gasoline (mobile sources) and natural gas and light oil (stationary sources). For other fuels with greater nitrogen content (i.e., heavy oil and coal used by larger boilers), NO_x is also formed by the oxidation of the nitrogen in the fuel. For coal, approximately 50% of the NO_x emissions are formed in this way and in extreme cases up to 80% of the NO in the exhaust gas is associated with the fuel nitrogen.

Because of different specific heats, nitrogen content, excess air requirement, etc., of different fuels, each fuel has a different NO formation potential per BTU. As shown in Table III-2, the combustion of coal (high nitrogen and excess air requirement) produced more NO_x per BTU than a clean gaseous fuel such as natural gas. Thus for the same heat input rate (10^6 BTU/hr) a coal-fired combustion unit would typically produce greater NO_x emissions than a natural gas or oil-fired unit.

QUESTION - Should the impact of stationary source fuel switches required by the Energy Supply and Environmental Coordination Act of 1974 (ESECA) be considered in the development of the NO_x control strategy?

ANSWER - Since the NO_2 problem is typically an urban problem and most ESECA fuel switches will be required for utility boilers, the location of power plants in the study area should be reviewed to determine if they will impact the urban area. Power plants 20 miles or more from an urban problem area generally will have minor impact on the urban problem area on an annual basis. If the source is expected to impact upon the problem area, the increase in NO_x emissions resulting from oil or gas-to-coal fuel switches should be considered as an emission increase that must be offset by other NO_x emission reductions. One factor to consider is that boilers which are combusting oil or gas but were originally designed for coal-firing emit substantially less NO_x than a furnace designed for oil or gas-firing. This is because the combustion

TABLE III-2

NO_x EMISSIONS PER BTU OF HEAT PRODUCED

Fuel (Nitrogen Content)	Type of Unit	Emission Potential ($\#NO_x/10^6$ BTU)
Coal	Utility/Large Industrial	
	Cyclone (Pulverized)	2.08
(1-2%N)	Wet Bottom (Pulverized)	1.25
	General (Pulverized)	0.75
	Industrial/Commercial	0.63
	Domestic	0.25
Oil	Utility	
	General	0.75
	Tangential	0.36
(0.1-0.5%N)	Industrial/Commercial	
	Horizontal	0.57
	Tangential	0.28
	Domestic	0.09
Gas	Utility	0.57
	Industrial	0.11 - 0.22
(Negligible %N)	Commercial	0.11
	Domestic	0.08

chamber designed for coal firing would be much larger than needed for oil or gas combustion and this large size tends to reduce NO_x emissions because of the reduced flame temperature. The important point is that if these low NO_x producing boilers switch to coal, this will result in a greater increase in NO_x emission rate than expected based on established emission factors. This is because the baseline NO_x emissions for the gas or oil-fired boiler (designed for coal) is substantially less than indicated by emission factors for gas or oil-firing of boilers designed for these fuels (See Table III-3).

TABLE III-3

UTILITY BOILERS* - FUEL SWITCHING

(NO_x Emissions lbs $NO_x/10^6$ BTU)

Fuel	Boiler Designed for Referenced Fuel	Boiler Designed For Coal Firing
Coal	0.9	0.9
Oil	0.7	0.3
Apparent Emission Increase from Fuel Switch	0.2	0.6
Actual Percent Increase	28.5%	200%

*Front Wall Fired

QUESTION - Historically, what type of NO_x emission trends have been observed?

ANSWER - NO_x emission rates have generally increased since 1940 principally because of the increase in number of motor vehicles and fossil fuel-fired stationary sources in use (see Figure III-3).

For the overall period 1940 to 1970, the average growth rate of NO_x emissions from motor vehicles and stationary fuel combustion sources were very similar, being 4.8 percent per year, respectively. Over the period 1940 - 1960, however, the average road vehicle emission growth rate was 4.9 percent and the stationary fuel combustion source growth rate was only 2.0 percent. During the period 1950 to 1970, these trends were reversed, and the road vehicle emission growth rate decreased to 4.6 percent while the rate for stationary fuel combustion sources increased to 7.3 percent. Over the last 10 years through 1970, NO_x emissions from steam-electric power plants increased at a rate of 7.4 percent per year.

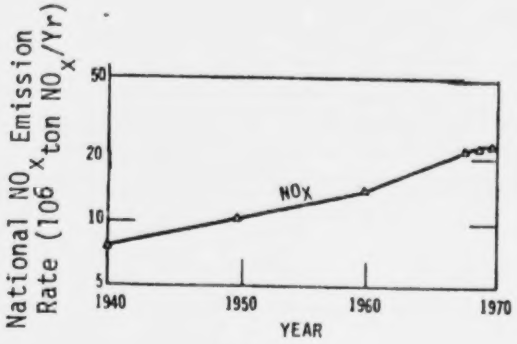


Figure III- 3- Nationwide emissions for NO_x (1940 - 1970). *

---

*A much more detailed discussion, including tables and methodology, is presented in Nationwide Air Pollutant Emission Trends, 1940 - 1970, AP-115

- NO_x Control Technology -

QUESTION - What is considered to be reasonably available control technology for stationary sources of NO_x?

ANSWER - The greatest activity in developing NO_x control technology has been with utility type boilers and nitric acid plants. Reasonably available control technology exists for both of these source categories. Utility type boilers are typically the largest NO_x stationary source emission category and in those areas where additional control is needed, these sources should be analyzed for NO_x control potential. NO_x control techniques are more advanced for gas and/or oil-fired boilers than coal-fired boilers. Listed below are reasonably available NO_x control techniques:

(a) Utility type boilers (greater than 250 x 10^6 BTU/hr heat input) - Combustion modifications

1. Lower excess air
2. Staged combustion
3. Burner modification or replacement
4. Flue gas recirculation (for gas or oil-fired boilers with recirculation provisions)

(b) Nitric Acid Plants - Catalytic Decomposition

QUESTION - Can significant NO_x emission reduction be expected to result from combustion modifications to existing utility type boilers?

ANSWER - Generally, yes. Table III-1 lists typical NO_x emission reduction factors that can be expected to be achieved (up to 50% or greater reduction in NO_x emissions).

Table III-4

NO_x LEVELS AND TYPICAL NO_x REDUCTIONS RESULTING FROM COMBUSTION MODIFICATION TO UTILITY TYPE BOILERS

			% NO_x REDUCTION WITH COMBUSTION MODIFICATION			
Boiler Type	Fuel	Uncontrolled NO_x, ppm*	LEA	LEA + Staging**	FGR	25% Load Reduction
Tangential	Gas	100-350	37	24-72	67	Typical NO_x reductions for boilers with a 25% load reduction are: Gas: 30% Oil: 10% Coal: 18%
Tangential	Oil	100-350 (600)	28	20-55	10-40	
Tangential	Coal	300-600	27-49	24-59	-	
Front Wall	Gas	130-700 (1500)	15-23	23-72	-	
Front Wall	Oil	250-550 (650)	19-35	26-45	31-46	
Front Wall	Coal	425-850	11-29	34-53	-	
Horizontally Opposed	Gas	400-950 (1500)	15-21	34-71	-	
Horizontally Opposed	Oil	200-500	3-9	19-40	-	
Horizontally Opposed	Coal	400-900	21-28	34-48	-	
Cyclone	Oil	300-500	10-16	-	-	
Cyclone	Coal	500-1200	-	-	-	

---

*ppm @ 3% O_2, dry basis LEA - Lower excess air FGR - Flue gas recirculation

**Variations of staged combustion. Includes two-stage, off-stoichiometric firing and/or biased firing.

QUESTION - What is considered to be achievable NO_x control technology for stationary sources?

ANSWER - NO_x control techniques which are not widely applied at the present time or which are not presently available but which are expected to be available (i.e., achievable) in the next few years include the following:

(a) Utility type boilers (greater than 250 x 10^6 BTU/hr heat input) - Combustion Modification

(1) Water or steam injection (oil or gas-fired)

(2) Preheat reduction

(3) Derating can be considered as a potential NO_x control measure but it should be reviewed on a case-by-base basis considering its effectiveness and feasibility.

(4) Firebox enlargement

(b) Small and medium-size Commercial/Industrial boilers (less than 250 x 10^6 BTU/hr heat input) - Burner modification or replacement

(c) Gas turbines

(1) Water and steam injection

(2) New combustor designs

(d) Stationary internal combustion engines - exhaust gas recirculation, turbo-charging with after cooling

(e) Chemical process (ammonium nitrate, fertilizer, explosive production, etc.) - caustic scrubbing, NO_x incineration in reducing atmosphere, etc.

(f) Industrial combustion processes (metallurgical, kilns, glass production) - combustion modification

QUESTION - If achievable NO_x emission limitations for stationary sources in conjunction with the FMVCP are not adequate to provide for attainment of the NAAQS for NO_2, what type of additional control measures should be adopted?

ANSWER - All achievable NO_x control technology for existing NO_x sources must be required if necessary and be submitted by July 1, 1977.

All other measures needed to attain and maintain must be submitted no later than July 1, 1978. These "other measures" should be comprehensive and innovative where needed, and should include items such as land use measures, transportation controls, transit improvements, zoning ordinances, building codes, inspection/maintenance programs for stationary and mobile sources.

Transportation Control Measures (TCM's)

Although it is thought unlikely that NO_x control will be a key determinant in the foreseeable future, NO_x emission reductions can be obtained from some of the TCM's for CO and/or Ox but the measures used must be carefully analyzed to assess the amount of NO_x control achieved. For example, retrofit of exhaust gas recirculation (EGR), vaccum spark advance disconnect (VSAD), or gaseous fuel conversion can directly reduce NO_x emissions. However, inspection/maintenance programs (I/M), if not specifically designed for NO_x, may have little or no effect on NO_x emissions.

NO_x emission reductions can also be obtained from reductions in vehicle miles traveled (VMT). Methods to reduce VMT include traffic restrictions, limited access zones, traffic-free zones, street closing and other similar measures. VMT can also be reduced through mass transit improvements such as express bus-carpool lanes, improved bus service, and rapid rail service. See Section F - Transportation Control Plans for more detailed information on this subject.

Stationary Source Control Measures

NO_x reductions from stationary combustion sources must be required as necessary. Such measures may include innovative energy conservation measures such as requiring (1) increased thermal insulation and storm windows and doors, (2) the use of power plant reject heat, (3) the use of central heating units for residential and commercial space heating and other energy saving measures. Additionally, a fuel tax on the nitrogen or BTU content of fuel may be useful to encourage conservation measures.

ADDITIONAL INFORMATION - See Air Quality Maintenance Planning and Analysis, Volume 4: Land Use and Transportation Considerations (EPA-450/4-74-004).

QUESTION - Will the application of combustion modifications to reduce NO_x emissions from utility type boilers effect emissions of other criteria pollutants?

ANSWER - The application of reasonably available NO_x control techniques (combustion modifications) to fossil fuel-fired steam generators are usually related to changes in the design of the boiler and/or burner configuration. Any of the combustion modifications presented in this document can usually be used to reduce NO_x emissions to meet most NO_x emission limitations. The flue gases leaving the boiler (firebox) area can be treated for other pollutants as required. One of the techniques for NO_x control, reduction of excess air, may increase smoke but the amount does not become significant unless very low excess air rates are used. This is balanced by the fact that as these pollutants increase, boiler efficiency is reduced, which is a waste of BTU's and the danger of explosion increases. This situation is usually watched closely and not tolerated by boiler operators, especially today. Utility boilers are less affected than industrial or smaller boilers because they normally have higher heat release rates. The use of reasonable and achievable combustion techniques for NO_x control should not affect the operation or efficiency of a control device used to control other pollutants.

QUESTION - How is NO converted to NO_2 in the atmosphere?

ANSWER - Although there are many atmospheric reactions involving NO - NO_2 transformation, only a few of the mechanisms are predominate in the basic conversion processes. The NO emitted into the atmosphere by sources combines with oxygen (O_2), ozone (O_3) or some type of organic compound to form NO_2. The NO_2 in the atmosphere can be photodisassociated by sunlight to form NO. While these NO - NO_2 reactions are in process, both NO and NO_2 may also be removed from the reactive mechanisms by combining with organic and/or inorganic radicals to form nitrates (such as PAN) which are photochemically unreactive.

QUESTION - Does HC control have any effect on ambient NO_2 concentrations?

ANSWER - Available laboratory studies have indicated that changes in the non-methane hydrocarbon/nitrogen oxides (NMHC/NO_x) ratio for an area may influence NO_2 concentrations. The studies indicated that if HC reductions exceed NO_x reductions, thus reducing the NMHC/NO_x ratio, peak NO_2 concentrations may be reduced but the annual average NO_2 concentration may increase. However, the NMHC/NO_x relationship is preliminary, hence it is not recommended that HC emissions be considered in an NO_x control strategy at this time.

QUESTION - Are any existing stationary sources required to continuously monitor NO_x emissions? If so, which sources?

ANSWER - Yes. On October 6, 1975, the Agency promulgated regulations (40 FR 46240) requiring the revision of SIP's to include requirements for the continuous monitoring of emissions from certain categories of stationary sources. Included in these regulations was the requirement for the monitoring of NO_x emissions from fossil fuel-fired steam generators and from nitric acid plants in AQCR's where the Administrator has specifically determined that a control strategy for NO_2 is necessary. A minimum size of 1,000 x 10^6 BTU/hour heat input for boilers and 300 tons/day (100% acid) production capacity for nitric acid plants was also established for these monitoring requirements. The regulations are complex and the reader is referred to applicable Federal Register for specific details. Any NO_x SIP revisions that have been determined to be needed shall include emission monitoring requirements for regulated sources.

Revisions to SIP's to require continuous emission monitoring must be submitted by the States to Regional Offices by October 6, 1976. The State regulations may allow an additional 18 months after EPA approval of the SIP revisions for sources to procure, install, and begin operating the monitoring instruments. Quarterly reports of (1) emissions in excess of SIP emissions limitation, and (2) the monitoring system downtime must be submitted by the sources to the States.

QUESTION - Are new stationary sources of NO_x required to monitor emissions?

ANSWER - Yes. The October 6, 1975, Federal Register (40 FR 46250) contains regulations under 40 CFR, Part 60, New Source Performance Standards, requiring all new fossil fuel-fired steam generators greater than 250 x 10^6 BTU/hour heat input and new nitric acid plants to continuously monitor their emissions of NO_x. Certain boilers, those capable of demonstrating operation during performance tests at below 70% of the emission standard, are exempted from the NO_x monitoring requirement. Sources must submit quarterly reports of excess emissions and monitoring system downtime to EPA Regional Offices.

SECTION A

HISTORY OF NO_x CONTROL UNDER THE CLEAN AIR ACT

Under the mandate of Section 109 of the Clean Air Act as amended (1970), the Administrator, on April 30, 1971, promulgated in the Federal Register (36 FR 8186) as Part 410 of 42 CFR, national ambient air quality standards (NAAQS) for particulate matter, sulfur oxides, carbon monoxide, photochemical oxidants, hydrocarbons (oxidant guide), and nitrogen dioxide. These air quality standards were to be attained and maintained in all AQCR's through the implementation of various emission limitations as specified by each State in their State Implementation Plan (SIP) for each Air Quality Control Region (AQCR) within a State. The NAAQS set for nitrogen dioxide were 100 $\mu g/m^3$ (0.05 ppm), annual average, for both the primary and secondary standard conditions. A 24-hour average standard for NO_2 of 250 $\mu g/m^3$ (0.13 ppm) was proposed but not promulgated because "No adverse effects on public health or welfare have been associated with short-term exposure to nitrogen dioxide at levels which have been observed to occur in the ambient air", at that time. A subsequent recodification on November 25, 1971, resulted in the NAAQS being contained in 40 CFR 50.11.

SIP's

SIP requirements were published on August 14, 1971, as 42 CFR, Part 420 and were recodified as Part 51 of 40 CFR on November 25, 1971. These requirements included, in Section 51.14, the requirement that all AQCR's where measured annual arithemetic average ambient NO_2 concentrations were greater than 110 $\mu g/m^3$, be designated Priority I. It was assumed that emission reductions resulting from the Federal Motor Vehicle Control Program (FMVCP) would reduce ambient levels to the standard (100 $\mu g/m^3$) by 1975, thereby not requiring control strategies to be developed for those AQCR's only slightly in excess of the NAAQS for NO_2 (110 $\mu g/m^3$ vs. 100 $\mu g/m^3$). Ambient air quality data used in determining the priority classification of the AQCR's in relation to NO_2 were generally based on the Jacobs-Hochheiser measurement technique. In the absence of measured air quality data, priority classifications were to be determined by population, i.e., AQCR's with an "urban place" population (1970) of greater than 200,000 would be classified Priority I for NO_2. A total of 47 AQCR's (19%) of the 247 AQCR's were classified Priority I, 25 (53%) of those AQCR's being interstate AQCR's. All other AQCR's were classified Priority III.

CONTROL STRATEGY REQUIREMENTS FOR NITROGEN DIOXIDE

Each Priority I AQCR was required to submit a plan which set forth a control strategy that provided the degree of emission reduction necessary for attainment and maintenance of NAAQS.

The emission reductions necessary to attain NAAQS for NO_2 standards were to be calculated with the use of the proportional model. Control strategy requirements for NO_2 were based upon the following measures (as needed):

(a) the utilization of the FMVCP for NO_x;

(b) consideration of any additional reduction in NO_x that would be an indirect result of a transportation control plan designed either for the control of carbon monoxide or photochemical oxidants; and

(c) the application of reasonably available control technology (RACT) on stationary sources of NO_x (e.g., power plants and nitric acid plants).

Should the combination of measures (a) (b) and (c) not demonstrate attainment and maintenance of the NO_2 standard, the original SIP control strategy was to also include the use of RACT for the control of stationary sources of hydrocarbons. If these measures were adopted, it was expected that the NO_2 standard would be attained.

It should also be noted that no TCP's* were required solely for the control of NO_x. It was believed that automotive emissions of NO_x did not contribute a large enough portion of the total NO_x emissions in an area such that a TCP designed specifically for NO_2 would be an efficient method to address NO_x control.

The NO_x control strategy requirements were amended late in 1971 (36 FR 25233, December 30, 1971) to delete the requirement for RACT for control of hydrocarbons from stationary sources. This change was based upon a reappraisal of information on the role of hydrocarbons in the atmospheric conversion of NO to NO_2 resulting in the conclusion that the reduction of hydrocarbons from stationary sources did not play a significant role in the reduction of long-term (annual) ambient NO_2 concentrations. With the deletion of this requirement, it was assumed that the NO_2 standard would be achieved if control measures (a) (b) and (c), identified above, were implemented.

---

*TCP = Transportation Control Measures

APPROVAL/DISAPPROVAL OF SIP's

On May 31, 1972, EPA published in the FR (37 FR 105, at 10842) notifications of approval and disapproval of State Implementation Plans submitted by States earlier in the year. Included in the Federal Register were notices of disapproval for the NO_x control strategies for the 21 AQCR's listed in Table A-1. The predominate reason for these disapproval actions was that the SIP did not require the application of RACT for stationary sources of NO_x within AQCR's with NO_2 problems.

To correct the inadequacy of these SIP's, EPA proposed regulations on June 14, 1972 (FR 11826), to require the use of RACT in AQCR's requiring NO_x control strategy. The AQCR's in Table A-1 would be made subject to EPA promulgated regulations if the State did not adopt approvable regulations before EPA promulgation. In this same FR notice, EPA acknowledged that there was some difficulty with the routine field use of the Jacobs-Hochheiser ambient monitoring technique and, because of that fact, the proposed regulations would not go into effect until July 1, 1973. Similarly, States that had adopted NO_x regulations would not be expected to require compliance before any EPA promulgated regulations. In the interim, further ambient measurements would be made to affirm the validity of the Jacobs-Hochheiser method.

MEASUREMENT CONTROVERSY

In the FR of June 14, 1972, at 11826, the Administrator took note of the fact that there were problems associated with the routine field use of the Jacobs-Hochheiser method, the method designated as the federal reference method for NO_x (see Appendix F, 40 CFR, Part 50). The problem with the reference method was caused by two factors that had become

TABLE A-1

21 AQCR's WITH DISAPPROVED NO_x CONTROL STRATEGIES AS OF MAY 31, 1972*

AQCR NO.	AQCR NAME	AFFECTED STATES
015	Phoenix-Tucson	Arizona
024	Los Angeles	California
042	Hartford-New Haven-Springfield	Massachusetts
043	New York-New Jersey-Connecticut	New York, New Jersey
045	Philadelphia	Pennsylvania, New Jersey
070	St. Louis	Missouri
085	Omaha-Council Bluffs	Nebraska
115	Baltimore	Maryland
123	Detroit-Port Huron	Michigan
151	Scranton	Pennsylvania, New Jersey
160	Rochester	New York
162	Buffalo	New York
195	Altoona	Pennsylvania
196	Harrisburg, PA	Pennsylvania
197	Pittsburgh	Pennsylvania
214	Corpus Christi-Victoria	Texas
215	Dallas-Fort Worth	Texas
216	Houston-Galveston	Texas
220	Salt Lake City	Utah
223	Norfolk	Virginia
225	Richmond	Virginia

*The control strategies for Atlanta (GA), Washington, D.C. (MD), Flint (MI), Toledo (NI), Memphis (TN), and Seattle (WA) AQCR's were also disapproved but were later approved (Sept. 22, 1972 and Oct. 28, 1972) after the respective states submitted additional information.

apparent during a reevaluation of the method. First, the method was found to have a variable collection efficiency--the range was from about 50% to 70% at low levels of NO_2 to about 15% at high levels of NO_2. The second problem was a positive interferance from NO that could cause NO_2 readings to be more than 100% greater than the actual value.

After an intensive laboratory and field investigation of the Jacobs-Hochheiser method (and other methods believed to be more accurate), it was concluded that the Jacobs-Hochheiser method was unreliable and should no longer be the reference method. Hence, in the FR on June 9, 1973, at 15174, EPA proposed to delete the Jacobs-Hochheiser method as the reference method. Three other reference methods, or "tentative candidate methods" were proposed. These included the arsenite bubbler (orifice), continuous chemiluminescence, and continuous Saltzman. Of these, the method with the greatest potential accuracy was considered to be the chemiluminescence technique.

Comments were solicited from the public and scientific community on the proposed new methodologies while lab and field investigations continued to determine the accuracy of the three candidate methods and other methodologies.

IMPACT OF MEASUREMENT CONTROVERSY ON SIP's

In addition to deleting the Jacobs-Hochheiser method as the federal reference method, the Agency took three other significant SIP related actions in the Federal Register in June, 1973, necessitated by the faulty Jacobs-Hochheiser data base upon which SIP's were based.

First, EPA proposed, on June 8, 1973 (38 FR 15180) to reclassify 43 of the 47 Priority I AQCR's for NO_2 from Priority I to Priority III. This was necessitated because current and valid NO_2 data was collected which indicated that no NO_2 problem existed in the 43 AQCR's. The remaining Priority I AQCR's were Los Angeles, Chicago, New York-New Jersey-Connecticut, and Wasatch Front (Salt Lake City). Because ambient NO_2 levels were significantly above the NO_2 standard in Los Angeles and Chicago, these AQCR's remained as Priority I AQCR's. Since the two remaining Priority I AQCR's (i.e., New York-New Jersey-Connecticut and Salt Lake City) had ambient levels only slightly above the national standards, it was proposed that additional information be collected in these AQCR's before any action was taken to either reclassify them to Priority III or to request a revised control strategy. Additionally, valid ambient data above 110 ug/m^3 had become available for Denver, which had originally been classified Priority III. Since the data were inconclusive, no action was taken at that time to reclassify Denver. However, it was proposed that additional data be collected in Denver.

Secondly, in the same FR action, EPA proposed to rescind its emission control regulations proposed on June 14, 1972, for 17 AQCR's and approve the State submitted control strategies for the attainment of NO_2 standards within these AQCR's. However, disapprovals of nitrogen oxides control strategies were retained for New Jersey-New York-Connecticut and the Wasatch Front AQCR's.

EPA held in abeyance the proposed regulations in these two AQCR's until final decisions could be made on the classification of these AQCR's. The Federal Register notice also indicated that States which had submitted NO_x regulations in AQCR's now classified Priority III were encouraged to rescind such NO_x control regulations. This action was taken since the regulations were developed on an inaccurate data base and current valid data did not support the need for such control.*

Thirdly, EPA proposed to change 51.14 (i.e., the requirements for approvable NO_x control strategy) so as to require an explicit demonstration that the national standard for NO_x would be attained in Priority I AQCR's. States would still be allowed to take credit for any NO_x reductions to be obtained through the FMVCP and any TCP necessary for controlling CO and/or O_x. Further, the Preamble to the proposed changes to Part 51 indicated that if a State could demonstrate NO_x reductions that may result through the use of hydrocarbon emission control, then such reductions could be considered in the demonstration of attainment of the NAAQS.

On May 8, 1974, at 39 FR 16344, the Administrator promulgated these three proposals with one exception. During the comment period, additional data had become available for the Baltimore AQCR which marginally indicated that that AQCR should not be reclassified Priority III. The data, however, were not conclusive that the AQCR should be designated Priority I. Hence, Baltimore was grouped with Denver, Salt Lake City and New York as AQCR's which required additional information prior to final reclassification.

---

*To date there have been few submittals for rescinding of NO_x control regulations.

As a result of the promulgations, control plans were needed for the two Priority I AQCR's (e.g., Los Angeles and Chicago). Hence the State of Illinois was required to submit within 4 months a demonstration that the approved control strategy for the Metropolitan Chicago AQCR was adequate to attain and maintain the national standard for nitrogen oxides. With respect to the Los Angeles AQCR, EPA had previously disapproved California's control strategy for nitrogen oxides, carbon monoxide and photochemical oxidants, and promulgated a transportation control plan. On February 6, 1974, the State of California submitted a plan revision for Los Angeles which provided a transportation control plan and a control strategy for nitrogen oxides. At the time of the Federal Register action, EPA (Region IX) was reviewing the plan to determine its adequacy in fulfilling the requirements of the revised §51.14 to demonstrate the attainment and maintenance of the nitrogen oxide standard for Los Angeles. Hence no further control strategy was required for Los Angeles at that time. In the July 12, 1976, Federal Register EPA called for a revision of the SIP NO_x control strategy for Los Angeles.

SECTION B

CURRENT STATUS OF AMBIENT NO_2 MEASUREMENT METHODS

Since the announcement that the Jacobs-Hochheiser method was potentially inaccurate, EPA has used other nitrogen dioxide measurement techniques in conjunction with the routine activities of the Continuous Air Monitoring Program (CAMP), the National Air Surveillence Network (NASN) and the Community Health and Environmental Surveillance System (CHESS). Data from these methods, as well as from laboratory investigations have been used to investigate the various methodologies. Four 24-hour bubbler methods have been operated at approximately 200 NASN sampling sites for various periods during 1972-73-74. These include: (1) sodium arsenite (orifice), (2) sodium arsenite (frit), (3) the triethanolamine- guaiacol-sulfite (TGS), and (4) triethanolamine (TEA) methods. In 1972, continuous chemiluminescence instruments were placed in 41 AQCR's and operated for approximately one year. Additionally, 20 chemiluminescence instruments were operated in various AQCR's with three additional instruments operated in Los Angeles under the CHESS network. Continuous Colorimetric (Saltzman) have been used at each of the six CAMP sites. In addition to these EPA sponsored monitoring projects, the state and local agencies have begun to expand the NO_2 ambient monitoring networks with various valid monitors.

In addition to collecting NO_2 information by various methodologies, work has continued to determine a new reference method for NO_2 to replace the Jacobs-Hochheiser method. Since the major problem with the Jacobs-Hochheiser method was the variable collection efficiency of the absorbing reagent, six alternate absorbing methods have been examined. These methods have undergone two independent studies at the Environmental Monitoring and Support Laboratory.

As a result of these studies, the chemiluminescence measurement principle and calibration procedure was proposed in the Federal Register on March 17, 1976, as the basis for the new reference method. The chemiluminescent technique was selected over the manual-type candidate methods primarily because analyzers based on this principle would have the capability of generating continuous, real time data rather than integrated data representing 24-hour time periods as in the case with the Arsenite and TGS manual methods. Technical evaluations and comments from the monitoring community were also considerations in the selection. It should be noted however that for determining compliance to the National Ambient Air Quality Standard for NO_2 - an annual arithmetic mean - integrated 24-hour bubbler measurements are adequate.

In addition, two 24-hour bubbler methods were found to be reliable and capable of producing valid air quality data. These are the TGS and sodium arsenite orifice methods. These two bubbler methods will be tested for equivalency as soon as a reference method is designated.

Data collected under proper operating conditions for these three methods, i.e., chemiluminescence, TGS, and arsenite orifice can be used directly in development of NO_x control strategies. Additionally, there are other methods in field use which are thought at this time to be capable of producing valid air quality data under the proper operating conditions, i.e., TEA, sodium arsenite frit and continuous Saltzman colorimetric. However, the likelihood of these methods providing valid data for an annual average is not as great as with the sodium arsenite orifice, TGS, or chemiluminescence methods. Therefore care should be taken to assure that the air quality data used for the control study is valid. If bubbler methods are to be used in SIP networks, the use of arsenite orifice and TGS bubblers should be encouraged. If continuous methods are to be employed, chemiluminescent analyzers should be encouraged although data collected with Saltzman colorimetric analyzer can be used if it is judged valid. (See Table B-1.)

In the case of the TEA method, it was found that the collection efficiency is low (around 50% with an orifice) and that a frit is necessary to obtain a more desirable high constant collection efficiency of 80%. Although data from this method would be acceptable for use in strategy analysis, other methods are available which have high constant collection efficiencies without the use of a frit. The frit is undesirable for the following reasons: it can become clogged which would result in inaccurate flow measurements; the use of pre-filters to capture particulate would interfere with SO_2 measurements if an NO_2/SO_2 sampling train was being used; and it is more expensive.

In the case of the sodium arsenite frit method, it was determined that the frit increased the collection efficiency by only approximately 5%. Because of the problems mentioned above with the use of frits, this method should be discouraged, although data already collected under proper operating conditions can be used for emission control strategy analysis.

TABLE B-1

NO_2 AMBIENT MEASUREMENT METHODS

Measurement Method (Method Code)	Comment
Instrumental	
(11) Modified Saltzman Colorimetric	Data can be used with caution *
(12) Saltzman Colorimetric	Data can be used with caution
(13) Coulometric	Data can be used with caution
(14) Chemiluminescence	Proposed Federal Reference Method Data can be used
Bubblers	
(71, 81, 91) Jacobs-Hochheiser	Data must not be used
(72, 82, 92) Saltzman Bubbler	Data must not be used
(84) Sodium Arsenite Orifice	Candidate Federal Equivalent Method Data can be used
(94) Sodim Arsenite - Frit	Data can be used with caution
(95) TEA	Data can be used with caution
(96) TGS	Candidate Federal Equivalent Method Data can be used

*User should be aware of the problems associated with the method and be assured that proper procedures were used in collecting data.

In the case of continuous colorimetric (Saltzman) analyzers, results of tests indicate a method bias, slow response time (about 15 minutes) and negative ozone interference for certain monitors. Because of these problems, the use of chemiluminescent analyzers should be encouraged. However, data obtained from analyzers using this measurement principle may still be valid for use in emission control strategy analysis for the following reasons:

1. Since the ozone interference noted in some monitors is negative, any NO_2 values obtained will tend to be conservative.

2. The ozone interference is significant only at high O_3:NO_2 ratios (32% negative interference at 3:1 O_3:NO_2 ratio) which occur over a limited part of the day and usually over one or two seasons of the year. Thus, the impact of this interference on annual averages of NO_2 should be small in many areas of the country.

3. A slow response time is not important when only annual averages are of interest. The impact would be insignificant on the annual average. However, short-term averages (e.g., 1-hr.) could be affected significantly.

4. Some users of analyzers (i.e., California/Los Angeles) using the colorimetric principle claim they have been unable to detect significant ozone interferences. Thus, it is possible that specific models may not be as prone to ozone interference as others.

Any data collected from instruments using the Jacobs-Hochheiser procedure should not be used for strategy analysis. Anyone using Jacobs-Hochheiser bubblers should be encouraged to switch to the sodium arsenite orifice or TGS procedure as soon as possible. A more detailed discussion of ambient NO_2 measurement method can be found in Comparison of Methods for Determination of Nitrogen Dioxide in Ambient Air (EPA-650/4-75-023).

The following section contains a more complete discussion of each method.

NO_2 MEASUREMENT METHODS

1. Sodium Arsenite Procedure (ARS), orifice - Bubbler (Method No. 84)

Principle and Applicability

Nitrogen dioxide is collected by bubbling ambient air through a sodium hydroxide-sodium arsenite solution to form a stable solution of sodium nitrite. The nitrite ion (NO_2^-) produced during sampling is reacted with phosphoric acid, sulfanilamide, and N-1-(naphthyl) ethylenediamine dihydrochloride to form an azo-dye and then determined colorimetrically.

The method is applicable to the collection of 24-hour samples in the field and their subsequent analysis in the laboratory.

Interferences

Nitric oxide (NO) is a positive interference. The presence of NO can increase the NO_2 response by 5 to 15 percent of the NO_2 sampled.

The interference of sulfur dioxide is eliminated by converting it to sulfate ion with hydrogen perioxide before analysis.

Evaluation

The method when followed is a precise procedure for measurement of NO_2 on a 24-hour average basis, and is sufficiently accurate provided the average 24-hour NO and/or CO_2 concentrations do not exceed 310 $\mu g/m^3$ and/or 500 ppm, respectively. The probability of these concentrations being exceeded in ambient air is low (less than 5%). Data from this method are considered valid and can be used as the basis of a control strategy.

2. TGS-ANSA Procedure - Bubbler (Method No. 96)

Principle and Applicability

Nitrogen dioxide (NO_2) collected by bubbling air through a solution of triethanolamine (T), O-methoxyphenol (guaiacol) (G), and sodium metabisulfite (S). The nitrite ion (NO_2^-) produced during sampling is determined colorimetrically by reacting the exposed absorbing reagent with sulfanilamide and 8-anilino-1-naphthalenesulfonic acid ammonium salt (ANSA). The method is applicable to the collection of 24-hour samples in the field and subsequent analysis in the laboratory.

Interferences

At a NO_2 concentration of 100 $\mu g/m^3$, the following pollutants, at the levels indicated do not cause interferences: ammonia, 205 $\mu g/m^3$; carbon monoxide, 154,000 $\mu g/m^3$, formaldehyde, 750 $\mu g/m^3$; nitric oxide, 734 $\mu g/m^3$; phenol, 150 $\mu g/m^3$; ozone, 400 $\mu g/m^3$; and sulfur dioxide, 439 $\mu g/m^3$.

A temperature of 40°C during collection of sample had no effect on recovery.

Evaluation

The method is an accurate, precise procedure for measurements of NO_2 in ambient air when the specified analysis procedure is followed closely. The method has more than adequate sensitivity for ambient measurement for 24-hour sampling periods. However, the method does not appear to be sensitive enough for short-term sampling. Data from this method are considered valid and can be used as the basis of a control strategy.

3. Chemiluminescence Method - Instrumental (Method 14)

Principle and Applicability

Atmospheric concentrations of nitric oxide (NO) can be measured by the chemiluminescent reaction of ozone (O_3) with NO at reduced or near atmospheric pressure. Nitrogen dioxide (NO_2) is measured as NO in the system after conversion of NO_2 to NO. Air samples are drawn directly into the analyzer to establish a NO response; then a switching valve directs the sample air through the converter where the NO_2 is converted to NO. The photomultiplier measures the light energy resulting from the chemiluminescent reactions of NO and O_3. By subtracting the NO signal from the $NO+NO_2(NO_x)$ signal, the amount of NO2 is determined. The subtractive process is accomplished electronically. Total time for both measurements is less than 1 minute.

The method is applicable to the measurement of NO_2 at concentrations in the atmosphere ranging from 9.4 to 18,800 ug/m3 (0.005 - 10 ppm).

Interferences

The chemiluminescent detection of NO with O_3 is not subject to interference from any of the common air pollutants, such as O_3, NO_2, carbon monoxide (CO), ammonia (NH_3), or sulfur oxides (SO_x).

When the instrument is operated in the NO_x mode, any compounds that may be oxidized to NO in the thermal NO2 converter are potential interferents. The principal compound of concern is ammonia; however, this is not an interferent for converters operated at less than 330°C. Unstable nitrogen compounds such as peroxyacetyl nitrate (PAN), organic nitrites, decompose thermally to form NO and may represent minor interferences in some polluted atmospheres.

Evaluation

The chemiluminescent method is a precise and accurate procedure for measurement of NO_2 in ambient air when used by an experienced operator. The method has more than adequate sensitivity for ambient measurements. Data from this method are considered valid and can be used as the basis of a control strategy.

4. Colorimetric Method (Saltzman) - Instrumental (Method 11)

Principle and Applicability

This method is based on a specific reaction of nitrite ion (NO_2^-) with diazotizing-coupling reagents. The absorbance of the azo-dye is directly proportional to the concentration of NO_2 absorbed.

This method is applicable to the measurement of NO_2 at concentrations in the ambient air from 18.8 to 1880 µg/m3 (0.01 - 1 ppm).

Interferences

Interferences from other gases that might be found in the ambient air have been reported to be negligible ; however, most interferent studies have been done on manual procedures and may not be applicable to continuous methods. Recent studies indicate that ozone (O_3) produces a negative interference as follows: ratio of O_3 to NO_2 1:1 = 5.5 percent, 2:1 = 19 percent, and 3:1 = 32 percent.

Evaluation

The results of the collaborative test demonstrates a collaborator dependent method bias which cannot be quantitated. The method has a slow response time and possesses a negative ozone interference. The method does have an acceptable lower detectable limit and adequate precision. Until the problems discovered in the collaborative test are resolved, additional monitoring using this method should not be initiated. However, after reviewing data available from this method, it may be found satisfactory for control strategy development.

Status of Selection of New NO_2 Reference Method

As a result of these tests, the chemiluminescence measurement principle and an associated calibration procedure was proposed as the basis for a method to supercede the original reference method. The chemiluminescent technique is recommended over the manual-type condidate methods primarily because analyzers based on this principle would have the capability of generating continuous, real time data rather than integrated data representing 24-hour time periods as in the case with the arsenite and TGS manual methods. Technical evaluations and comments from the monitoring community were also considerations in the selection. It should be noted however that for determining compliance with the National Ambient Air Quality Standard for NO_2 - annual arithmetic mean- integrated 24-hour bubbler measurements are adequate.

The continuous chemiluminescence measurement principle and calibration procedure were proposed in the Federal Register on March 17, 1976, as the new reference method. This proposed action specified only a measurement principle and calibration procedure, not a reference method per se. For a specific analyzer to be designated as a reference method for NO_2, it would be required to utilize the measurement principle and calibration procedure, meet all specifications and other requirements of Part 53 (i.e., EPA reference and equivalency requirements that will also be promulgated shortly) and be designated as a reference method under provisions of Part 53. Analyzer manufacturers would test their own respective analyzers against the specifications and requirements and then would submit the results to EPA. Analyzers satisfying all of the Part 53 requirements would be designated as reference methods. It would, therefore, be possible to have several reference methods for NO_2. In addition, other methods or measurement principles will be designated as equivalent methods. A three-month period is being allowed for manufacturers to best their instruments and submit them with the test results for reference

Method designation. If no instruments are submitted in that period, EPA will designate an instrument which EPA itself will have tested and found satisfactory as the reference method. The FEDERAL REGISTER action schedule needed to accomplish these tasks is outlined below.

Schedule for Establishing NO_2 Reference Method

Date	Action
3/17/76	Propose continuous chemiluminescence measurement principle and calibration procedure (40 CFR Part 50).
3/17/76	Propose reference and equivalency requirements (40 CFR Part 53).
10/76	Promulgate measurement principle and calibration procedure; promulgate reference and equivalency requirements.
2/77	Designate reference methods (40 CFR Part 50) and identification of acceptable commercial instruments.
3/77	Designate equivalent methods (40 CFR Part 53). (Arsenite and TGS 24-hr. bubbler methods are expected to be designated as equivalent methods.)

SECTION C

NO_2 FORMATION PROCESSES AND CONTROL STRATEGY MODELING

Emissions of NO_x and NO_2 Formation

Most man-made sources of nitrogen oxide, NO_x, emit primarily nitric oxide, NO. Some point sources, such as nitric acid plants and TNT plants, however, directly emit mostly nitrogen dioxide, NO_2, into the atmosphere. The reaction mechanism for the conversion of NO to NO_2 conversion is complex and is a function of many factors including the hydrocarbon concentrations, hydrocarbon reactivity, ultraviolet radiation and ambient temperature.

The importance of hydrocarbons in the conversion of NO to NO_2 is the photochemical production in the air of organic radical species and ozone which oxidize the NO to NO_2. Ultraviolet light acts both to photochemically dissociate NO_2 to NO and at the same time to help produce the species that oxidize NO to NO_2. As a result, ambient air never has just NO or just NO_2, although summer afternoon air often has 10 to 15 parts of NO_2 per part of NO. The conversion of NO to NO_2 is slower in the winter than in summer because of lower temperatures. A parameter that has been identified in laboratory studies as important in the conversion process is the hydrocarbon to NO_x ratio. It appears that if the ratio is reduced by reducing the hydrocarbon emissions more than the NO_x emissions, the peak NO_2 concentrations will decrease but the nonpeak NO_2 concentrations may actually be increased due to the lessening of the extent of removal processes with the hydrocarbons.

It is not known how the 24-hour and annual average concentrations will be affected. Although insufficient data is currently available to require consideration of the hydrocarbon to NO_x ratio in control strategy development work, the hydrocarbon reduction associated with the oxidant control strategy may become of interest in the future and eventually may need to be considered with respect to its possible impact on the NO_2 control strategy.

Under most conditions, NO is mostly converted to NO_2 within a few hours. During this period, NO_x emitted into the atmosphere is constantly dispersing while the NO_2 is forming. In an urban area this fact can allow a portion of the NO_x emitted from tall stacks to be brought to the ground and a portion of the NO_x emitted from motor vehicles to disperse upward before the NO-NO_2 conversion is completed. As the NO_2 is formed in large urban areas, it becomes rather uniform in concentration in relation to the area due to the significant NO_x emissions throughout the urban area. For the 24-hour average and for the annual average, sharp NO_2 concentration gradients are therefore not observed in urban areas in contrast to the situation for directly emitted pollutants such as CO and SO_2.[1]

Isolated point sources outside of urban areas, whether large or small NO_x emitters, have their greatest impact near the source with relatively less impact on distant cities where NO_x attainment problems are generally experienced. Generally, most isolated fossil fuel-fired power plants have a minor local impact and a negligible impact on annual average NO_2 concentrations at a distance greater than 20 to 30 miles. The time period required for NO-NO_2 conversion and transport to a metropolitan area allows for diffusion of the NO_2 to such an extent that its impact on the urban area is minor. Thus, sources of NO_x emissions 20 or more miles distant from the fringes of an urban area generally need not be considered as an important emission source in relation to the urban area, even though their emission rates may be large. Large emission reductions from such isolated sources usually will not be effective in reducing NO_2 concentrations in the urban area. Other factors such as wind persistence, topographical features restricting transport in certain directions, etc., should also be considered in analyzing NO_x - NO_2 source receptor relationships and defining "isolated" sources.

Natural background concentrations of NO_2 resulting from bacterial and plant actions should also be considered in strategy development. Such concentrations are generally about 8 $\mu g/m^3$ (.004 ppm)[2] annual average.

CONTROL STRATEGY MODELING

A key element in the evaluation of a control strategy is an adequate methodology for relating pollutant emissions to ambient air quality. A commonly used technique is an atmospheric simulation model which is a mathematical description of the pollutant transport, dispersion and transformation processes that occur in the atmosphere. In its simplest form, such a model relates ambient pollutant concentrations (χ) to pollutant source emissions rates (Q) and a background concentration (B).

$$\chi = KQ + B$$

The variable K is a function of atmospheric conditions and the spatial relationships between a source and a receptor.[3]

With the aid of a simulation model, it is possible to estimate systematically the variations in pollutant concentration which would result from alternative degrees and types of emission control. If each control strategy can be stated in terms of specific emission reductions, then a simulation model can be used to investigate the cost effectiveness of each strategy. Although simulation models may not be capable of indicating the air quality impact of individual control strategies with precision, simulation models provide a measure of the range and relative significance of air quality changes which may result from various strategies.

The simplest of the models used to project air quality is the proportional or rollback model. In the past this model has been used for NO_x control strategy review and development for urban areas. It is recommended that this simple model along with measured air quality data continue to be used as the basis for NO_x planning. While other models may be applicable to special cases, such as isolated point sources, or may attempt to explicitly account for the photochemical production of NO_2, such models have not been adequately validated at this time.

The proportional model assumes that the dispersion parameter (K) does not vary with time or with the source-receptor relationship and that changes in NO_x emissions will be uniform across the area. Thus the relationship of emissions (Q_2) and air quality (x_2) at some future time to base year emissions (Q_1) and air quality (x_1) can be expressed by the following proportionality which accounts for the natural background NO_2 concentration (B).

$$\frac{x_2 - B}{x_1 - B} = \frac{Q_2}{Q_1}$$

Fundamentally, the rollback model assumes that there is a direct cause and effect relationship between the rate of emission of the pollutant and its concentration in the atmosphere. If, for example, the rate of emissions is reduced by 95 percent, it is expected that the non-background component of atmospheric concentrations will be reduced by 95 percent. The use of this linear relationship does not imply that the chemical relationships leading to NO_2 formation in the atmosphere are linear. It is, therefore, not necessary to know what percent of NO_x is converted to NO_2. The implicit assumption is that the ratio between emitted NO_x and ambient NO_2 is fixed and that it will not change from year to year as NO_x concentrations change.

The proportional model can be used to determine the reductions in NO_x emissions which are necessary to reduce NO_2 ambient concentrations from x_1 to x_2 if no change in NO_2 background occurs. To calculate the percent reduction in NO_x emissions, R, the proportional model can be rewritten in the rollback form, as follows:

$$R = \frac{Q_1 - Q_2}{Q_1} \times 100 = \frac{x_1 - x_2}{x_1 - B} \times 100$$

where x_1 = SIP design value (representative annual average NO_2 concentrations in base year).

B = NO_2 background concentration (8 $\mu g/m^3$)

x_2 = C = NAAQS for NO_2 (100 $\mu g/m^3$)

R = Percent reduction in NO_x emissions required

The rollback model is applicable to annual NO_2 concentrations on an urban area basis for which appropriate data are available. Input to the rollback model requires total area-wide emissions for the base year and for the future year of interest. An annual NO_2 concentration representative of air quality for the area of interest is also necessary. It should be noted that the proportional model can only be used to estimate concentrations at sites where representative air quality data are available. However, because of the small NO_2 gradients observed in most urban areas, this limitation becomes of much less importance for NO_2 than for other pollutants.

Because of the number of different types of sources which emit NO_x, an expansion of the simple rollback equation has been made. This expansion is called Modified Rollback (See Appendix A - Modified Rollback). Modified Rollback is a technique for considering a variety of NO_x source categories and growth factors. It can be expressed as

$$\frac{C - B}{x_1 - B} \sum_{i=1}^{N} (Q_i)_{\text{base year}} = \sum_{i=1}^{N} (Q_i G_i)_{\text{future}}$$

where

G = a growth and control factor, i.e., the ratio of NO_x emissions at or after the attainment date versus the NO_x emissions in the base year, N = the number of source categories,

i = a particular source category, e.g., light-duty vehicles, trucks, power plants and other stationary sources, etc.

In cases where the area-wide NO_x emissions are contributed by a variety of source types with differing emissions, growth rates and applicable controls, the modified rollback model permits a consideration of a variety of control strategies.

To apply this technique, the left side of the equation is evaluated with available data to determine an allowable NO_x emission rate. The right side of the equation is then evaluated for various control strategies until a strategy which demonstrates attainment is developed. Growth rates for mobile sources and for stationary combustion sources can usually be obtained from local planning agencies. Future emission reductions for mobile sources can be estimated from Supplement 5 to AP-42. Expected emission reductions for stationary sources depend on new source performance standards and local regulations for NO_x emissions on the date that these regulations take effect.

The rollback models are applicable anywhere for which there are basic data on area-wide emissions and representative air quality for a particular base year. The simple rollback model can be applied with hand calculations and is widely used. Modified rollback has been computerized and documented. A computer program and associated documentation on the "Modified Rollback Computer Program" have been made available to all EPA Regional Offices.

APPLICATION

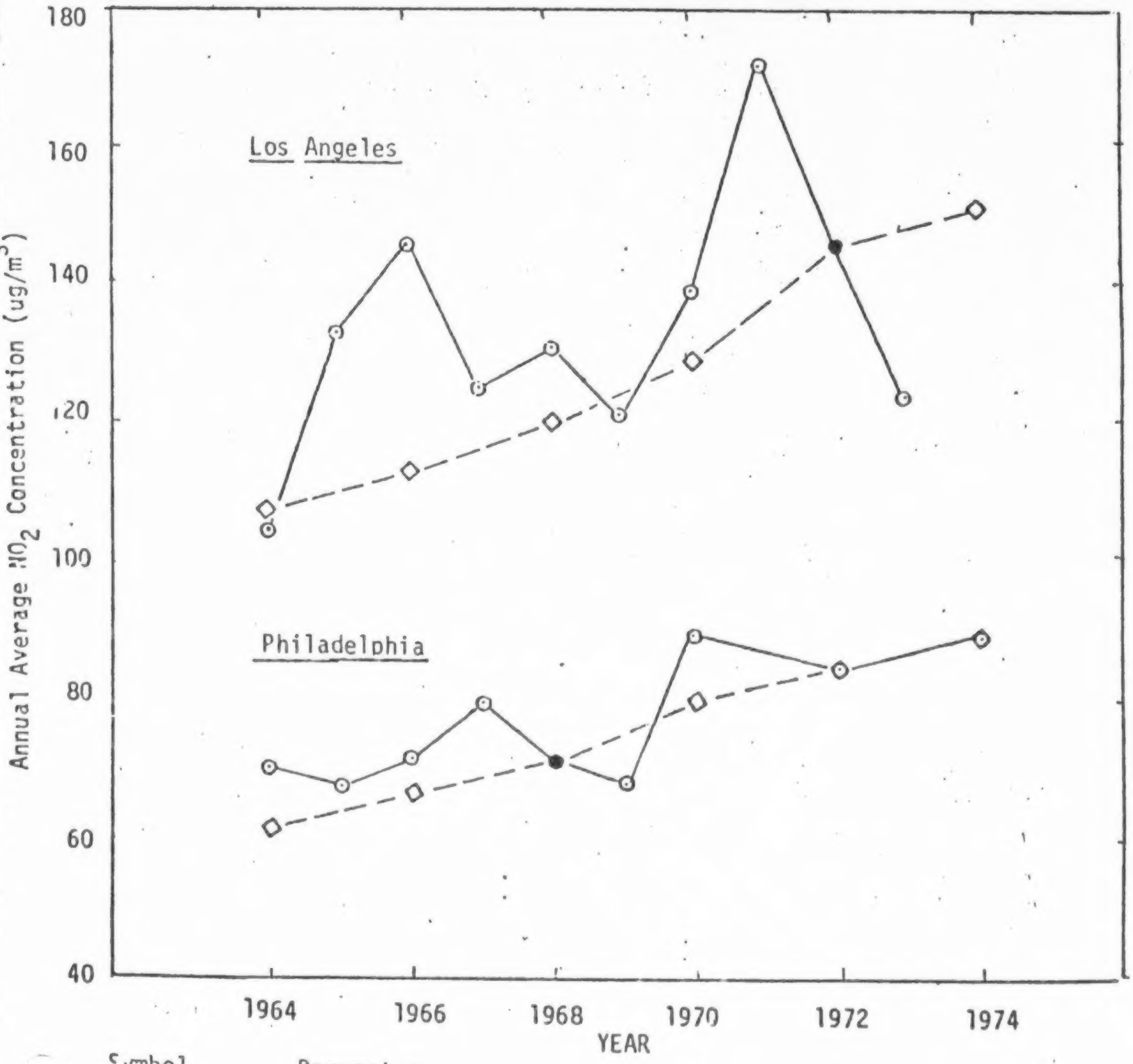
Figure C-1 presents projections and trends for nitrogen dioxide for Los Angeles and Philadelphia (Camp Stations). These annual average NO_2 concentrations were developed using the modified rollback technique. In general, Figure C-1 demonstrates that the modified rollback model and assumptions used with it provide an adequate representation of the actual air quality trends. The projections are smooth curves, whereas the measured air quality may change randomly from year to year because of meteorological factors. Any deviation between the projected values and the measured air quality may be due to errors in estimating and projecting emissions and changes in air quality.

OTHER MODELS

Because of the limitations of existing NO-NO_2 modeling techniques, MDAD, OAQPS is continuing to review available models to assure the best "state of the art" models are made available for NO_2 control strategy review and development work. The proportional model previously discussed is currently the method which is recommended for control strategy development work. If other superior NO_x models are identified by future OAQPS reviews, they will be made available to the Regions as soon as possible. AQDM, CDM, or other models may be used when evaluating point sources of NO_2, when the atmospheric photochemical reactions are not significant. If a more appropriate model is available, it may be used if approved by the Regional Administrator. Technical assistance on the application of these various models may be requested from MDAD, OAQPS.

FIGURE C-1

OBSERVED AIR QUALITY VS. MODIFIED ROLLBACK PROJECTIONS



Symbol	Parameter
⊙	Observed NO_2 Concentrations (Modified Saltzman Method)
◇	Projected NO_2 Concentrations (Modified Rollback Model)

REFERENCES

1. Martinez, E. L., and N. C. Possiel, "Report of NO_2 Distribution in Cities" Memo, October 10, 1975.

2. Air Quality Criteria for Nitrogen Oxides, AP-84, pp. 3-1 (1971).

3. Appendix A-40 CFR Part 51.

SECTION D

CONTROL OF OXIDES OF NITROGEN FOR STATIONARY SOURCES

Table of Contents

Page

BOILERS AND HEATERS D- 1

Utility Boilers D- 2

Tangentially-fired boilers D- 3

Front-wall firing furnaces D- 4

Horizontally-opposed firing furnaces D- 4

Cyclone furnaces D- 4

Split or divided furnaces D- 4

Commercial, Residential, and Industrial Boilers (CRI) D- 5

COMBUSTION MODIFICATIONS D- 7

Low excess air combustion (LEA) D- 7

Off-stoichiometric or staged combustion D- 8

Flue gas recirculation (FGR) D- 8

Water or steam injection D- 9

Preheat reduction D- 9

Firebox enlargement D- 9

Derating D- 9

Burner designs D- 9

Costs of Combustion Modifications D- 12

FLUE GAS TREATMENT (NO_x) D- 13

Dry Flue Gas Treatment D- 13

Wet Flue Gas Treatment D- 15

GAS TURBINES D- 16

STATIONARY INTERNAL COMBUSTION ENGINES D- 18

INDUSTRIAL PROCESSES D-19
  Nitric Acid D-19
  Catalytic Decomposition D-19
  Scrubbing D-20
  Molecular Sieves D-20
  Extended Absorption D-21
  Other Chemical Processes D-21
PETROLEUM AND NATURAL GAS PRODUCTION D-23
METALLURGICAL PROCESSES D-23
CEMENT, LIMESTONE, CERAMIC, AND GLASS PRODUCTION D-24
OTHER STATIONARY SOURCES D-24
SUMMARY OF NO_x CONTROLS D-25
GLOSSARY D-27

List of Tables
List of Figures

List of Tables

Table D-1. Analyses of Typical U. S. Coals and Lignite

Table D-2. Analyses of Typical Fuel Oil

Table D-3. NO_x Emission Levels from Uncontrolled Utility Boilers Compared to the New Source Performance Standards

Table D-4. Typical Baseline Emission Levels From Commercial and Residential Heating

Table D-5. NO_x Levels and Typical NO_x Reductions with Combustion Modification to Utility Boilers

Table D-6. Summary of Combustion Modification Techniques for Large Boilers

Table D-7. Estimated Investment Costs for Retrofitting Low Excess Air Firing to Existing Utility Boilers

Table D-8. Major Flue Gas Treatment Plants in Japan Using Selective Catalytic Reduction (Dry Process)

Table D-9. Major Flue Gas Treatment Plants in Japan Using Wet Scrubbing

Table D-10. Effectiveness of Combustion Modification on Gas Turbines

List of Figures

Figure D-1. Tangentially Fired Boiler
Figure D-1a. Details of Tangentially Corner Firing Systems and Flame Pattern
Figure D-2. Front Wall Fired Boiler
Figure D-3. Front Wall Fired Boiler
Figure D-4. Horizontally Opposed Fired Boiler
Figure D-5. Schematic Drawing of Cyclone Furnace
Figure D-6. Cyclone Fired Boiler
Figure D-7. 1973 Installed Equipment Costs of NO_x Control Methods for New Tangentially, Coal-Fired Units
Figure D-8. 1973 Installed Equipment Costs of NO_x Control Methods for Existing Tangentially, Coal-Fired Units
Figure D-9. Typical Gas Turbine Base Load NO_x Emissions
Figure D-10. Effectiveness of Water or Steam Injection in Reducing NO_x Formation in Gas Turbines

CONTROL OF OXIDES OF NITROGEN FOR STATIONARY SOURCES

Control technology for stationary sources can address NO_x by process changes or tail gas treatment. Process changes tend to be specific to source characteristics. Tail gas treatment has potential applicability to many sources but except for nitric acid plants, its use has been extremely limited to date. The greatest activity in NO_x control has been with utility boilers and nitric acid plants.

Process changes are commonly termed "combustion modifications". While still being refined, they are used widely for large boilers and other combustion sources in the United States. Flue gas treatment (FGT) systems are being investigated in the United States but most of the development work is being conducted in Japan.

BOILERS AND HEATERS

Nitric oxide (NO) is formed during combustion either from thermal fixation of molecular nitrogen in the combustion air (thermal NO) or from oxidation of chemically bound nitrogen in fuels (fuel NO). In the atmosphere, NO reacts slowly with oxygen to form nitrogen dioxide (NO_2). The main factors affecting NO formation in combustion sources are characteristics of the fuel burned, flame temperature, length of time the combustion gases are subjected to peak flame temperatures and excess oxygen.

Effect of Fuel Nitrogen

Recent studies [1,2,3,4,5] indicate that as much as half of the nitrogen in the fuel (oil and coal) can be converted to NO. It was also shown that the fraction of fuel nitrogen converted to NO decreases with increasing nitrogen content even though the magnitude of the NO increases. Excess air (oxygen) appears to have a strong effect on fuel nitrogen conversion but conversion is relatively insensitive to temperature. Much of the U. S. supplies of residual oil and coal are relatively high in nitrogen; therefore, it is important to give consideration to fuel characteristics when discussing combustion modifications. Tables D-1 and D-2 show the range of fuel nitrogen for various coals and fuel oil.

An extremely wide range of devices can be classified as boilers or heaters. For this document, only a minimal review of boiler terminology is presented such that the reader can differentiate between those factors that materially affect NO_x emissions. Many other publications treat boiler and heater technology in depth.

In broad categories, boilers and heaters can be differentiated by usage, fluids heated or vaporized, size, fuels burned, firebox design, firetube versus watertube, by the use or non-use of air preheaters, and by the manner in which they are constructed (field erected or packaged). Many of these factors affect NO_x emissions as do operational characteristics such as excess air, degree of air preheat, and firing rate.

For purposes of this paper we have segregated boilers and heaters into two groups which we term "utility boilers" and "commercial, residential, and industrial (CRI) boilers". There is some overlap since large industrial boilers are grouped with utility boilers and the smallest utility boilers are occasionally of the same design as CRI boilers.

Utility Boilers

Utility steam generators and large industrial boilers are differentiated from other types of boilers and heaters since they are much larger and produce significantly greater concentrations and quantities of NO_x than CRI boilers. These large units (generally greater than 250 million Btu per hour heat input) employ air preheaters such that firebox peak temperatures are about 500°F hotter than with CRI designs. Also utility boilers are almost always field erected, watertube designs as opposed to packaged units (built in the factory) typical of CRI installations. Furthermore, essentially all U. S. utility boilers are manufactured by four firms, Babcock and Wilcox, Combustion Engineering, Riley Stoker, and Foster Wheeler. Utility designs are limited but by and large those offered for new units reflect consideration of NO_x reduction techniques. Some designs inherently produce more or less NO_x. Typical new utility boilers are of 500 megawatts (output) capacity (4.5 x 10^9 Btu per hour heat input) and most are coal-fired. The largest industrial boilers are of about 750 million Btu per hour heat input. Units of 100 million Btu per hour and greater tend to be of the same general design as utility boilers.

Furnace design of utility boilers has a significant effect on NO_x emissions since it governs maximum temperature and residence time. Other factors being equal, thermal NO formation is a function of heat release rate (Btu per hour per cubic foot) and cooling rate (the rate at which heat is transferred from the combustion gases to water or steam). For example, dry bottom pulverized coal furnaces with relatively large fire boxes tend to produce less NO_x than wet bottom or slagging furnaces in which high heat release rates and high temperatures are necessarily required.

For purposes of NO_x emissions, utility and large industrial boilers are usually classified by furnace design. Major furnace designs are as follows:

> Tangentially-fired boilers have nearly square fireboxes with burners located in vertical rows in all four corners. The burners can be tilted up or down (to control superheat temperature) and are aimed slightly off of center to create a vortex pattern in the horizontal plane. Corner-fired boilers produce relatively lower NO_x

levels. They are manufactured by Combustion Engineering. Figure 1 shows a typical corner-fired boiler. Figure 1a shows details of a corner firing system configuration and flame pattern.[5/]

Front-wall firing furnaces (Figures 2 and 3) are designed with all burners firing horizontally from one wall normally considered the front of the furnace.

Horizontally-opposed firing furnaces (Figure 4) are designed with rows of burners firing horizontally from the front wall and other rows of burners firing horizontally from the rear wall.

Cyclone furnaces (Figures 5 and 6) are a type of slagging furnace in which coal and combustion air are introduced in a tangential pattern. Burning occurs at high heat release rates such that ash becomes molten and is tapped from the bottom of the boiler. Cyclone furnaces require coal with ash of low softening point. They produce greater concentrations of NO_x than almost any other design and for this reason are seldom installed at new sites.

Split or divided furnaces are divided by a wall of steam or water tubes. Such furnaces are usually front-wall fired or horizontally-opposed fired.

Uncontrolled emissions from utility boilers tend to be lowest for tangentially fired units and highest for cyclone furnaces. Other factor being equal, NO_x emissions are lowest for gas firing and greatest for coal burning. However because of constraints on natural gas and fuel oil, almost all new utility boilers probably will be fired with solid fuel. Ranges of uncontrolled emissions are listed in Table D-3 for principal utility boiler designs. The relationship between NO_x concentration and the NSPS is a function of fuel heat content and chemical makeup (the latter governs the volume of products of combustion generated by a unit weight of fuel). The coal cited in Table D-3 is of relatively high heating value (13,100 BTU per pound) and doesn't necessarily reflect the coal burned in the boilers at which the data were measured.

Commercial, Residential, and Industrial (CRI) Boilers

Commercial and residential boilers, small and medium size industrial units, and residential warm air furnaces are almost always assembled at the factory and shipped to the user as a package. For the most part the boilers are of firetube design but the largest and smallest often are of watertube construction. Until the recent oil crisis, all except the oldest CRI boilers were fired with natural gas or fuel oil.

Because of the absence of air preheating and because of their smaller size (shorter residence time at high temperature) CRI boilers inherently produce less NO_x than their larger counterparts. There have been only limited efforts until recently to characterize emissions from CRI boilers.

It is known that there are wide variations in CRI firing rates and in burner maintenance and adjustment. The firing rate and firebox characteristics probably have a strong effect on NO_x emissions but the influence of these factors has not been evaluated for the many CRI designs available in the United States. Also there is little uniformity in such important design parameters as firebox heat release rate. However, in comparison to utility boilers, CRI units probably are fired at lower rates, i.e., lower percentages of manufactures maximum load rating; this factor tends to reduce NO_x emissions below those which would be predicted from emission factors.

In addition, CRI boilers normally receive less maintenance and operator care than utility boilers such that combustion is less complete and heat transfer is less efficient. Precision adjustments, such as are necessary with many combustion modification techniques, are generally not workable for retrofitting CRI boilers. The effect of maintenance and operator care on NO_x emission in unclear. Where combustion is incomplete, NO formation is likely to be inhibited. On the other hand, the extremely wide variation of excess air often observed at CRI boilers might produce more or less NO_x emissions.

Baseline or uncontrolled emission levels for typical commercial and residential heating boilers are listed in Table D-4. These values represent units of less than 100 x 10^6 BTU heat input, some appreciably smaller.

COMBUSTION MODIFICATIONS

Principal combustion modifications are measures that reduce maximum flame temperatures, minimize oxygen concentration, or reduce residence time at peak temperatures. Combustion modifications include: (1) low excess air (LEA), (2) off-stoichiometric combustion (OSC), (3) flue gas recirculation (FGR), (4) water or steam injection, (5) preheat reduction, (6) burner design, (7) firebox enlargement or revamping, and (8) derating.

Of these options, LEA and OSC are the most frequently employed since they are applicable to most existing boilers, are less costly than other options, and represent no fuel penalty (in fact they can improve fuel efficiency). FGR is the next most likely alternative particularly for new boilers or those already equipped with FGR components. Options (4) and (5) present measurable energy penalties. Option (6)--burner design--is in reality a broad area in which LEA, OCS, and FGR principles are usually employed within the burner. Options (7) and (8) are corollaries with firebox modification usually applicable to new boilers only; derating is a means of achieving the same effect--less heat release per unit volume--at existing boilers. It should be pointed out that option (7) and (8) are unattractive from an economic point of view.

Low excess air (LEA) combustion has been used successfully with all fuels in a variety of furnaces. By reducing oxygen availability at the burner(s), both thermal and fuel NO levels are reduced. The degree of reduction is a function of furnace design and fuel characteristics as well as excess air. Practical excess air levels are limited by the formation of incomplete combustion products (CO, partially oxidized hydrocarbons, and carbon). Care must be taken in reducing oxygen to avoid unacceptably low levels where boiler vibrations, slagging, fireside corrosion, and in extreme cases explosions (CO) can be encountered.

Off-stoichiometric or staged combustion covers a wide range of techniques designed to limit the availability of oxygen during combustion. Two-stage combustion is a type of OSC which involves reducing air through the main burners to about 90 to 95 percent of stoichiometric and adding the balance of the combustion air through separate ports beyond (usually above) the highest burner zone. OCS variations are (1) to fire lower sets of burners in a fuel rich mode and upper burners fuel lean and (2) to use staggered configurations of fuel rich and fuel lean burners with some burners acting only as air ports. On existing boilers, a load reduction will result if the active fuel burners do not have the capacity to carry the fuel required for full load. Most furnaces constructed recently (1970's) are or have been designed with overfire air ports so that all fuel burners are active even with OCS in operation.

Flue gas recirculation (FGR) is accomplished by recycling part (typically 15 to 30 percent) of the exhaust gases through the burners into the primary combustion zone. This method is generally restricted to low nitrogen fuels (gas and low-nitrogen fuel oils) because FGR is most effective for thermal NO. FGR reduces the flame zone temperature and the concentrations of oxygen needed for NO production. Flue gas recirculation requires greater capital investment than LEA and OCS methods because of the need for high temperature fans and ducts and large space requirements for the modifications. However, for those boilers originally designed with FGR (for superheat control), costs of retrofitting are reasonable.

Water or steam injection is used primarily on oil or gas-fired systems where thermal NO predominates. Water or steam injected into the combustion zone reduces flame temperatures and prevents the formation of thermal NO. This technique has the greatest operating costs of the combustion modification schemes with a fuel and efficiency penalty of about 3 to 5 percent.

Preheat reduction is an NO_x reduction technique that has been used only sparingly because of the energy penalty. It is applicable only to utility steam generators and large industrial boilers which employ heaters to impart about 500°F incremental heat to combustion air. With present boiler designs, reducing air preheat would cause significant reductions in thermal efficiency and fuel penalties of up to 14 percent. This technique would be feasible if means other than air preheat were developed to recover heat from 300 to 800°F gases.

Firebox enlargement is a design change usually feasible only for new boilers because of economic penalties. At any given heat input, increasing the cooling rate in the furnace tends to lower peak temperatures and reduce NO formation. Firebox enlargement like derating is most effective where high heat release rates are employed. It is usually not feasible for slagging furnaces.

Derating will reduce NO formation in almost all types of boilers provided the same or lower excess air rates are maintained. Nonetheless, this method reduces heat or power output. It does not adversely affect heat rate, in fact, thermal efficiency is normally improved by derating.

Burner designs of a wide variety have been offered to reduce NO formation. For the most part, they are designed for Commercial/Industrial boilers and employ LEA, OCS, or FGR principles. The aim is to strike a balance between minimum NO formation and acceptable combustion of carbon and hydrocarbons in the fuel.

The Japanese appear to lead the way with several commercial low-NO_x burner designs in operation and under development. Considerable development work is underway in the U. S. by several companies, some under EPA contracts. To date, new optimized design burners appear to have the capability of reducing NO_x concentrations 40 to 65 percent from conventional burner designs on gas and oil fuels. No data were available for coal burners but preliminary studies indicate a substantial reduction will be achieved by new coal burner designs. The new burners are designed to attain good controlled mixing of fuel and air in a pattern that keeps the flame temperature down and dissipates the heat quickly. Burners can be designed to control flame patterns thus minimizing peak temperature reaction time between nitrogen and oxygen. Other designs internally recirculate part of the combustion gases or have fuel rich and fuel lean sections within a burner to reduce flame temperatures and oxygen availability. New burner designs, especially for large utility type boilers, have not been completely proven. Additionally, the effectiveness of replacement burners for small domestic heating units has not been fully determined.

Burner design modifications have the major advantages of not requiring redesign of boilers or combustion chambers, not necessitating load reduction, and possible applicability to many types of boilers. The disadvantages are that some burners may have to be custom designed for specific fuels, some designs (large burners) are difficult to manufacture, and some may only be applicable to a limited number of boilers. However, improved burner design may well replace the external combustion modifications now in use and achieve significantly lower NO_x emissions.

For the most part, burner designs are considered applicable to CRI boilers. Nonetheless, Babcock and Wilcox, one of the principal U. S. vendors of utility boilers, has indicated its intent to use a dual register burner as the prime means of achieving NSPS requirements for NO_x in new boilers.[6/]

Table D-5 summarizes NO_x reductions that can be achieved with utility boilers. The combination of low excess air and off-stoichiometric firing is seen to provide over 50 percent reductions in many instances. Nonetheless, the degree of reduction is affected strongly by the base line NO_x level before combustion modifications were performed. For those cases where levels were initially low, reductions of only 20 to 30 percent were accomplished.

The summary in Table D-6 lists several pertinent aspects of combustion modification techniques applied to utility-size boilers.

Costs of Combustion Modifications

Cost data have been developed principally for utility boilers with emphasis on coal firing. The least expensive technique, low excess air, represents a capital cost of less than $1.00 per installed kilowatt and has no energy penalty. Cost of LEA are presented in Table D-7 for gas, oil, and coal firing.[7/]

Costs of more extensive combustion modifications are presented in Figures D-7 and D-8. This information was developed in a 1973 study by Combustion Engineering Company and relates principally to tangentially fired boilers.[8/] However, it is believed reasonable to apply the cost figures to wall-fired boilers as well.

FLUE GAS TREATMENT (NO_x)

Flue gas treatment (FGT) processes reduce NO_x emissions from combustion sources either by decomposing it to nitrogen and water or oxygen or by removing it from the gas stream. Work on these systems in the United States is being funded by EPA but the major work is being conducted in Japan both for wet and dry FGT methods. FGT is not considered a reasonable control technology at this time. FGT is more advanced for clean gas streams (gas-fired boilers) than dirty gas streams (oil or coal-fired), but the decreased use of natural gas for firing utility type boilers will reduce its potential applicability. For "dirty gas streams", (SO_2 and particulate), FGT are still in the developmental stage.

Dry systems are operated at about 700°F and generally employ flue gas additives and catalysts. Wet systems employ a wider variety of chemicals and are operated at 100 to 120°F, the same temperatures as scrubbers use to remove SO_2.

Dry Flue Gas Treatment

Dry processes are more developed than wet systems, particularly for "clean" flue gas streams, that is, gases from the burning of natural gas or LPG. Large clean gas streams in Japan have been in operation for over a year. However, dirty gas streams have been piloted successfully and several prototype plants are now being constructed to treat gases from oil and coal-fired boilers.

The dry systems which have been developed in Japan are catalytic reduction (selective and non-selective), catalytic decomposition, electron beam radiation, and absorption. Selective catalytic reduction has been the most widely used process, however, selective non-catalytic reduction of NO_x with ammonia has been demonstrated commercially in Japan reducing NO_x emissions by 70 percent.[9/]

The selective catalytic reduction (SCR) process normally uses ammonia and a metal catalyst to reduce NO_x selectively to nitrogen and oxygen. It is termed "selective" because it affects only NO_x. SCR can reduce NO_x concentrations in a clean gas stream by more than 90 percent. Particulates and SO_2 tend to poison the catalysts. Compared to the wet process, the dry process is simple, requires less space, presents no troublesome by-products, and requires no reheating of tail gases. However, the dry process has yet to prove itself on a dirty gas stream of commercial scale. If the dirty gas is scrubbed to remove SO_2 before FGT, it will have to be reheated from about 100°F to 700°F. Excess ammonia may combine with SO_3/SO_2 and cause a visible plume. Ammonium bisulfate is also corrosive to mild steel. Large amounts of ammonia may be required which means an increased consumption of natural gas (to produce ammonia). Like wet processes, ammonia requirements are proportional to the quantity of NO_x removed. Thus, combustion modifications are likely to be used to reduce NO_x levels as much as possible before treatment in FGT systems.

Table D-8 shows the selective catalyst reduction processes on commercial and pilot plants in operation or in the construction stage in Japan. Two large plants, being constructed by Sumitomo Chemical and Hitachi Shipbuilding will treat "dirty gas" streams.

A pilot plant on "dirty gas" (oil fired) has been operated by Sumitomo for over 4,000 hours reportedly without serious problems. Electrostatic precipitators are used to remove dust and prevent contamination of the catalyst. More than 85 percent NO_x removal has been reported for this pilot unit.

Alkaline scrubbing, molecular sieve absorption, and catalytic reduction processes have been identified as possible NO_x control techniques. Most of these hold promise primarily for specialized applications where NO_x concentrations are high or where local considerations require stringent control.

A selective noble metal catalyst process using ammonia was explored on a pilot scale through an EPA contractor. The pilot plant using natural gas accumulated about 2,000 hours of testing and achieved NO_x reductions of 90 percent with essentially no catalyst degradation. Further tests have been conducted using fuel oil and/or sulfur-containing flue gases. These tests indicate that platinum is not satisfactory for flue gases containing SO_2. A final report is in preparation.

Another study for EPA has been conducted for the technical and economic assessment of various catalytic processes for NO_x control.[7] Lab scale tests on simulated flue gas (no fly ash) investigated several operating variables and catalysts. The major emphasis was on selective NO_x-ammonia, non-noble catalyst systems. These parametric studies indicated NO reductions of 60 to 95 percent at inlet concentrations of 250 to 1,000 ppm.

Wet Flue Gas Treatment

In Japan,[10] the wet processes generally use an oxidation step and many yield by-products, i.e., nitric acid, potassium nitrate, ammonium sulfate, calcium nitrate, and gypsum, some of which have questionable marketability. Some wet processes reduce NO_x to the elements and yield no by-products. Currently, the Japanese are investigating flue gas treatment processes aimed at the elimination of both NO_x and SO_x; this may be the major advantage of a wet system. Wet systems are better suited than dry systems for use on dirty gas. Major disadvantages of wet systems are (1) expensive oxidizing agents and/or energy inputs are needed in proportion to the quantity of NO_x removed, (2) some processes create a wastewater problem, (3) demand for by-products may be limited, and (4) many processes require SO_2 removal first to reduce consumption of NO_x removal chemicals.

In 1975, there were 12 different wet processes being developed in Japan at pilot plants and small commercial plants (100 to 25,000 cubic meters per hour). The largest systems reportedly are treating 32,000 to 100,000 cubic meters per hour of flue gas. No firm data are available as to NO_x removal efficiencies but the range appears to be from 60 to 90 percent. Japanese systems are directed at meeting stringent levels which are dictated by ambient air quality standards. Table 9 lists plants in Japan using wet process FGT systems.

GAS TURBINES

Gas turbines for stationary application range from 40 to 87,000 horsepower (about 65 Mw) with larger units being designed. Uncontrolled NO_x emissions are a function of turbine size and fuel type. Increasing the turbine size increases the NO_x concentrations primarily due to higher combustion temperatures usually employed and to increased residence time at high temperatures. Oil-fired turbines have higher NO_x concentrations than gas-fired units. Typical uncontrolled NO_x concentrations for No. 2 fuel oil and gas-fired turbines are shown in Figure 9. Variances between turbines of equal size are attributed to design differences and/or fuel characteristics.

Most combustion modifications for turbines using gas or distillate oils are based on methods to reduce peak temperatures since the majority of NO_x emissions from these fuels are thermal. However, some gas turbines are being designed to fire residual oils where the conversion of fuel nitrogen to NO could be significant.

NSPS studies being conducted by EPA indicate that water or steam injection results in the least NO_x emissions. Significant reductions in NO_x can be achieved using these methods but some turbine efficiency (1-3 percent) is lost when using water. Further, the water used in turbines has to be very clean (less than 5 ppm total solids) requiring water preparation facilities. Providing water or steam of acceptable quality to turbines at remote locations may be a problem.

NO_x reduction is strongly influenced by the water or steam to fuel ratio. Equally important is the injection technique. With optimum injection techniques and a water or steam to fuel ratio of 0.6 to 1.0, NO_x reductions of 50 to 75 percent have been achieved with oil firing and 60 to 90 percent with gas firing (Figure D-5).1/ Table 10 shows the effectiveness of combustion modifications on gas turbines using the various techniques. Cost data for NSPS are being developed and will be available in the near future.

The proposed new source performance standard for gas turbines, i.e., 55 ppm (gas) and 75 ppm (oil) at 15 percent O_2, should be achievable by adjustments in injection ratios for the size turbines discussed in this section.11/

There are about 14 dry control techniques or combinations thereof under development for gas turbines; however, none have been put into field operation. The dry techniques are: primary zone leaning; exhaust gas recirculation; premixed, prevaporized, and well-stirred combustors; variable geometry; and external combustors. Development work on dry control techniques is being aggressively pursued by turbine manufacturers because it is felt that they will be more economical and attractive to users. Development data indicate that dry control systems may consistently achieve concentrations of 15 to 25 ppm NO_x at 15 percent oxygen. Gas turbines may also be amenable to control by FGT systems. However, for a given heat input, FGT will be more costly than for boilers since turbines use appreciably greater ratios of excess air.

STATIONARY INTERNAL COMBUSTION ENGINES

Stationary internal combustion engines (ICE) sizes range from a fractional horsepower (lawn mower type) to large multi-cylinder units of over 1,000 horsepower. Diesel engines are included in this category.

NO_x emissions from these sources can range from 100 to 3,000 ppm depending upon engine type, size, design, fuel, load, fuel to air stoichiometry, etc.[12/] In fact, NO_x emissions from ICE probably are subject to more variables than any other stationary combustion source.

Control techniques for ICE are many and varied but only two are being applied to production ICE and these only infrequently. They are exhaust gas recirculation on gas/gasoline engines and turbo-charging with after-cooling mainly on large diesel engines.

Other methods being studied to reduce NO_x emissions are derating, water injection, modified fuel injection timing, variable compression ratio, optimum fuel/air ratio, retarding ignition, catalytic converters, and exhaust treatment. Laboratory studies indicate that 35 to 60 percent reductions of NO_x concentrations may be achieved; however, the effectiveness of many of the methods has yet to be demonstrated in actual operation and little is known if these methods are reasonable for existing sources. Proposed NSPS for stationary internal combustion engines will probably be stated in grams NO_x per horsepower per hour.[12/]

Preliminary annualized cost estimates on the exhaust gas recirculation system are approximately $200 per ton of NO_x removed.[12/] Cost estimates for other control techniques were not available for this report.

INDUSTRIAL PROCESSES

Compared to other major sources, NO_x emissions from these processes are considered minor. They often represent highly concentrated emissions (1,000 to 10,000 ppm NO_x) in low volume streams.

Nitric Acid

A typical uncontrolled nitric acid plant will release NO_x in the range of 1,000 to 3,000 ppm. Emissions above 3,000 ppm are considered uneconomical and can be reduced by simple process improvements. All the control technology systems to be discussed could be installed on many existing pressurized plants with costs the controlling factor as to which one to use for any particular plant.

Standards of performance for new nitric acid plants were promulgated in August 1971 allowing 3.0 pounds NO_x per ton of acid produced. The NSPS was based on catalytic decomposition systems as other control schemes were not developed. Today, other systems are available.

Catalytic Decomposition. Catalytic decomposition of NO_x to the elements nitrogen and oxygen is still the most prelevant control method used in the United States. All catalytic reduction processes use some type of fuel-reducing agent with natural gas and hydrogen being the most common. Energy generated from the exothermic reaction is usually recovered and used in the acid process. The catalytic reduction systems are basically designed for streams containing about 3,000 ppm. At lower concentrations, the processes may not be economically attractive because of lower energy recovery. Operating costs for 100 and 1,000 TPD plants are estimated respectively to be \$0.97 to \$0.70 per ton of acid; capital costs are estimated to be \$207,000 and \$830,000.[13/] Operating costs are directly related to the cost of fuel.

Scrubbing. Caustic scrubbing removes NO_x but few commercial installations use this process because of problems in disposing of the spent nitrate solutions which can create a serious water pollution problem. Removal of 90 percent of NO_x emissions have been reported by this process.

The Masar process uses a solution of urea to scrub NO_x; the nitrated solution finds use as a nitrogen fertilizer. Two commercial installations are using the process. Originally, the plants were reported operating at exit levels of about 200 ppm NO_x. Further tests conducted by an EPA contractor and an independent test laboratory showed NO_x concentrations in the range of 55 to 60 ppm from uncontrolled levels of about 1,800 ppm. The operating cost of this process is reported to be about 30 cents per ton of acid produced (1974 cost data). Ability to use the by-product is a major advantage.

Molecular Sieves. Two commercial plants use molecular sieves for NO_x control. They reportedly work well in acid plants where the tail gas is bone dry. The sieve converts NO to NO_2 which is absorbed in the sieve. Desorption produces an enriched NO_2 which is reused to produce more nitric acid. The increase in nitric acid production is reportedly about 2 to 3 percent.[13/]

A vendor has reported that during three-day performance tests on one commercial installation, 99 percent plus NO_x removal was achieved and outlet concentrations ranged from less than one ppm to 7 ppm. Since then, the typical daily average outlet concentration has been less than 50 ppm with instantaneous concentrations ranging from 0 to 104 ppm NO_x.

A second installation is reporting outlet levels of about 180 ppm NO_x. EPA is funding monthly testing of these installations for two years to confirm the vendor's guarantee. At one installation a plant malfunction damaged the sieve such that it probably will not meet the guarantee but may still meet NSPS.[13]

Operating costs for plants of 100 and 1,000 TPD are estimated to be \$1.75 and \$1.35 per ton, respectively; the capital costs are about \$500,000 and \$4,100,000.[13]

Extended Absorption. The extended absorption process has a second absorption tower to receive tail gases from the first absorber and continue the absorption process. Unconfirmed reports indicate that emissions from this process will meet NSPS. For 100 and 1,000 TPD plants, operating costs are estimated to be \$1.53 and \$0.61 per ton, respectively and capital costs about \$1,200,000 and \$6,100,000.[13]

At small nitric acid plants, batch processes, storage facilities, or other specialty processes NO_x may be controlled by incineration. The emissions are burned by adding excess fuel; the NO_x acting as an oxidant is reduced to nitrogen. NO_x reductions of 75 to 90 percent have been estimated but not confirmed in plant operation. Fuel requirements are probably the main disadvantage of this system.[13,14]

Other Chemical Processes

Other chemical processes which are sources of NO_x include the production of ammonium nitrate, adipic acid, terephtholic acid, nitrobenzene toluene dissolyanate, commercial and military explosives, fertilizers, and other nitro-nitrate compounds.

Emissions usually occur in any of these processes at the step in which the nitric acid and other compound(s) are mixed or reacted. Emissions from ammoniated processes are usually negligible because the reactivity of ammonia is much higher than nitric acid and because a slight excess of ammonia is usually required for product formation (NH_4NO_3). In most other processes, it is economically attractive to capture all or most of the NO_x emissions for reuse because nitric acid represents one of the prime material costs.

In these specialty processes, caustic scrubbing or NO_x incineration in a reducing atmosphere may be used. Scrubbing with urea solutions may also be suitable. Control technology is sometimes difficult because the operations are intermittent in character. The specialty processes are relatively small but may cause local problems. Costs may vary widely.

NO_x emissions from industrial and military explosives (ammonium nitrate, TNT, nitroglycerin, others) are reported to range from 2.5 to 12 pounds NO_x per ton of product. Previous control techniques discussed can be applied to these processes.

NO_x can be released from fertilizer processes which use nitric acid for acidulation with phosphate rock. Only a few manufacturers produce nitric phosphates making this an infrequent problem. The reaction of the nitric acid with the carbon or organic material in the phosphate rock produces the NO_x emissions. The use of calcined rock will prevent the production of NO_x. For the acidulation step in fertilizer production scrubbers are used to remove particulates and fluorides; however, the scrubbers are not effective in controlling NO_x emissions. No emissions data are available but brown fumes which appear to be NO_2 are reported to occur. One company reported that urea (discussed previously) added to the acidulation mixture reduced fuming and eliminated the brown plume. Ammonium nitrate fertilizer (ammoniating processes) was discussed previously.[14/]

NO_x is evolved from metals pickling, bright-dipping copper, and the manufacture of tungsten filaments. Emissions reportedly can be reduced through the proper use of chemicals as well as charcoal absorption, catalytic reduction, and NO_x incineration.

PETROLEUM AND NATURAL GAS PRODUCTION

Oil and gas production, pipeline transportation, gas plant operation, and petroleum refining may be significant sources of NO_x emissions. NO_x emissions result from the combustion of fuel in boilers, heaters, CO boilers, internal combustion engines, and gas turbines. NO_x control technology for boilers and heaters, I.C. engines, and turbines has been discussed previously.

METALLURGICAL PROCESSES

NO_x from steel and metallurgical processes has to date drawn less attention from pollution control agencies than other pollutant emissions. NO_x emissions can be traced primarily to the combustion of fuels. At steel plants, NO_x is generated at the blast furnaces (stove), open hearth furnaces, coke plants, sinter plants, cupola furnaces, basic oxygen furnaces (BOF), and soaking pit furnaces. The phasing out of open hearth furnaces and the switch to electric steel production will reduce these emissions. This would transfer some NO_x generation to the power plant where effective NO_x control probably can be achieved.

Most of the NO_x produced in metallurgical furnaces is believed to be due to nitrogen fixation but fuel nitrogen may be important also. Little attention has yet been directed to the control of NO_x at steel plants but combustion modifications should be an effective technique.

CEMENT, LIMESTONE, CERAMIC, AND GLASS PRODUCTION

Cement, limestone, and ceramic kilns and glass manufacturing are other sources of NO_x that could be of significance. Little information on NO_x control or emissions is available. The majority of NO_x emissions comes from the large quantity of fuels burned at temperatures (1700^0 - 2900^0 F) usually needed for the operation of the processes. Combustion modifications to reduce peak temperatures would be expected to reduce NO_x emissions. However, since high temperatures are required on some of the processes switching to gas, modification of firing design, low excess air, incineration, or electric heating may be effective techniques.

OTHER STATIONARY SOURCES

Other sources of NO_x emissions are: refractory fiber material furnaces, perlite production furnaces, baking and drying ovens, spray driers, and welding machines (electric arc and oxyacetylene). Most of these processes create high temperatures conductive to the formation of NO. However, limited available data indicate that most of these are low NO_x emitters (7-40 ppm). Combustion modifications (mainly low excess air) or other treatment methods mentioned previously may be effective in reducing NO_x

emissions.

SUMMARY OF NO_x CONTROLS

Boilers and Heaters

1. Combustion modification techniques:
    - are available for new utility size boilers and to a lesser degree for retrofit of existing utility boilers,
    - are more advanced for gas and oil firing than for coal firing,
    - provide reductions of 30 to 60 percent in NO_x emissions from utility boilers, and
    - are more limited for CRI than for utility boilers with burner adjustments and new burner designs offering more promise to CRI operators than techniques which have been effective with utility boilers.
2. Burner adjustment and maintenance programs to improve combustion at existing CRI boilers may not reduce NO_x emissions and could increase them.
3. Flue gas treatment for NO_x:
    - is not considered a reasonable control technology for NO_x.
    - won't be available for oil and coal-fired boilers in the near future, and it is uncertain whether the processes can be perfected for use in the presence of SO_2,
    - probably will reduce NO_x levels by 80 or 90 percent,
    - may be extremely costly where inlet NO_x levels are greater than 250 ppm,
    - will have direct (wet processes) or indirect (dry processes) energy penalties,

- will have to be further investigated to determine their compatibility with flue gas desulfurization systems,
- may create ozone, ammonium-sulfur compounds, or other undesirable compounds in stack gases, and
- may generate liquid wastes containing nitrate or nitrite pollutants.

Gas Turbines

4. Water and steam injection can provide 50 to 75 percent reductions in NO_x from oil fired turbines and 60 to 90 percent for gas-fired turbines but only at fuel penalties of 1 to 3 percent.
5. Proposed new source performance standards can be achieved without water or steam injection.

Internal Combustion Engines

6. Limited study indicates that 30 to 60 percent NO_x reductions can be realized at internal combustion engines.

Nitric Acid Plants

7. Several techniques are available to achieve the new source performance standard level.

Other Sources

8. Many of the NO_x control schemes used for nitric acid plants are applicable to other industrial sources, particularly those sources which are operated under high pressures.
9. Flue gas treatment systems which are being developed for combustion sources should be applicable to almost all NO_x sources.

Glossary

Clean Gas Stream - Exhaust gases containing only negligible fractions of SO_2 and particulate, as from burning natural gas or LPG.

Combustion Modification - An alteration of the normal burner/firebox configuration or operation employed for the purpose of reducing the formation of nitric oxide.

Cyclone Furnace - A type of wet bottom furnace in which combustion takes place in cylindrical cyclone-separator-like burners. Ash becomes molten in the cyclone burners and flows to the bottom of the boiler where it is periodically tapped.

Derating - Reducing the heat input and power or steam output of a boiler below the level for which it was designed.

Dirty Gas Stream - Exhaust gases containing significant SO_2 and/or particulate, as from an oil or coal-fired combustion device.

Dry-Bottom Boiler - The common type of pulverized coal furnace employed at most new power plants. Temperatures in the firebox are maintained at a sufficiently low level that melting or slagging of the ash does not occur. Bottom ash is removed from the firebox in the dry state.

Excess Air - Any increment of air greater than the stoichiometric fuel requirement. With gas, oil, and coal-fired boilers, some excess air is used to assure optimum combustion.

Flue Gas Recirculation - A combustion modification in which a portion of the boiler exhaust gases are recirculated to the burners to inhibit NO formation. (FGR)

Flue Gas Treatment - A process which treats tail gases chemically to remove NO_x before release to the atmosphere. (FGT)

Fuel Nitrogen - Nitrogen that is chemically bound in the fuel.

Heat Release Rate - The rate of combustion per unit volume of firebox, typically in terms of Btu's per hour per cubic foot.

Low Excess Air - A combustion modification in which NO formation is inhibited by reducing the excess air to less than normal ratios.

Off-Stoichiometric Combustion - A combustion modification in which NO formation is inhibited by delaying the introduction of part of the combustion air, also termed staged combustion.

Stoichiometric Air - That quantity of air which supplies only enough oxygen to react with the combustible portion of the fuel.

Two-Stage Combustion - A type of off-stoichiometric combustion.

Wet-Bottom or Slagging Furnace - A type of furnace often used with older utility boilers in which the ash becomes molten and is tapped from the bottom of the furnace in the molten state.

Field-Erected Boiler - All components of a boiler are delivered to the site and assembled in the field. Mainly pertains to utility and large **industrial boilers.**

Packaged Boilers - These are usually CRI boilers that are smaller and more economically assembled at the plant, shipped to the boiler site, as one integral unit ready for operation after connection to water, steam, and power.

Heat Input - The product of the fuel feed rate and the higher heating value, e.g., 10 tons per hour of coal with a higher heating value of 25 x 10^6 Btu per ton provides a heat input of 250 x 10^6 Btu per hour.

Heat Output - The quantity of heat contained in the steam and/or hot water generated in the boiler, usually the product of the steam rate and the enthalpy of the steam.

Boiler Efficiency - $\frac{\text{Heat Output}}{\text{Heat Input}} \times 100.$

The overall figure reflects combustion efficiency, radiation and convection losses from the boiler and heat lost in exhaust gases.

Gross or Higher Heating Value - The heat generated by complete combustion of a fuel, always referenced to baseline temperature, e.g., 60°F. Heat available at the reference temperature is included in the higher heating value even if it is not practically available, i.e., heat of condensing water vapor.

Net or Lower Heating Value - The heat that is practically available from a fuel to generate steam or otherwise raise the temperature of the media receiving energy. The net heating value assumes complete combustion. It differs from the higher heating value in that heat of vaporizing water of combustion is considered an recoverable loss.

Table D-1. Analyses of Typical U. S. Coals and Lignite*

Rank	Anthracite	Bituminous	Subbituminous	Lignite
Analysis:				
Moisture, %	2-5	2-15	15-30	25-45
Volatile matter, %	5-12	18-40	30-40	25-30
Fixed carbon, %	70-90	40-75	35-45	20-30
Ash, %	8-20	3-25	3-25	5-30
Heating value, 10^3 Btu/lb	12-14.5	10-14	8-10.5	5.5-8
Sulfur, %	<1	0.5-5	1.5-3	0.5-2.5
Nitrogen, %	0.5-1	1-2	1-1.5	0.5-1.5

*Research Triangle Institute, "Effects of Transient Operating Conditions on Steam-Electric Generator Emissions", EPA-600/2-75-022, August 1975.

Table D-2. Analyses of Typical Fuel Oil*

	Distillate Oil		Residual Oil		
Grade	No. 1	No. 2	No. 4	No. 5	No. 6
Analysis					
Gravity, °API	35-42	30-35	23-25	18-22	12-16
Viscosity, Saybolt sec.	-	33-37	45-125	150-700	900-9000
Heating value, 10^3 Btu/gal	134-138	136-144	143-146	145-149	149-152
Sulfur, %	0.1-0.3	0.2-0.8	1-3	1-3	1-5
Hydrogen, %	12-14	12-14	11-12	10-12	10-12
Carbon, %	86-88	86-88	86-88	86-88	85-88
Nitrogen, %	<0.01	<0.01	0.1-0.5	0.1-0.5	0.1-0.5
Ash, %	0.01	0.01	0.01-0.1	0.01-0.1	0.01-0.3

*Research Triangle Institute, "Effects of Transient Operating Conditions on Steam-Electric Generator Emissions", EPA-600/2-75-022, August 1975.

Table D-3. NO_x Emission Levels From Uncontrolled Utility Boilers Compared to the New Source Performance Standards

Boiler Type	Fuel[a]	Uncontrolled		New Source Performance Standard	
		$lb/10^6$ Btu[b]	ppm at 3% O_2	$lb/10^6$ Btu	Equivalent ppm at 3% O_2
Tangential	Gas	0.14-0.50	100-350	0.2	141
Tangential	Oil	0.14-0.50	100-350	0.3	210
Tangential	Coal	0.44-0.88	300-600	0.7	498
Front Wall	Gas	0.18-0.99	130-700		
Front Wall	Oil	0.36-0.77	250-550		
Front Wall	Coal	0.63-1.26	425-850		
Horizontally Opposed	Gas	0.57-1.35	400-950		
Horizontally Opposed	Oil	0.28-0.72	200-500		
Horizontally Opposed	Coal	0.59-1.33	400-900		
Cyclone	Oil	0.43-0.72	300-500		
Cyclone	Coal	0.74-1.77	500-1200		

[a] Natural gas higher heating value 1,100 Btu/cu. ft.
No. 6 fuel oil higher heating value 18,000 Btu/pound.
Bituminous coal higher heating value 13,100 Btu/pound.

[b] Heat input based on higher heating value of fuel.

Table D-4. Typical Baseline Emission Levels From Commercial and Residential Heating[7]

Unit	Fuel	Emission Concentration, ppm 3% O_2, dry basis			
		NO_x as NO_2	CO	HC	Bacharach Smoke
Residential	Gas	70	15	3	0
Residential	No. 2 Oil	115	65	13	3
Commercial	Gas	80	20	9	0.2
Commercial	No. 2 Oil	100	4	3	0.9
Commercial	No. 4 Oil	390	7	3	2.6
Commercial	LSR*	260	3	5	2.9
Commercial	No. 5 Oil	290	16	4	3.0
Commercial	No. 6 Oil	415	10	5	3.9

*Low Sulfur Residual Oil (~1% S)

Table D-5.

NO_x LEVELS AND TYPICAL NO_x REDUCTIONS WITH COMBUSTION MODIFICATION TO UTILITY BOILERS[7/]

Boiler Type	Fuel	Uncontrolled NO_x, ppm*	% NO_x REDUCTION WITH COMBUSTION MODIFICATION			
			LEA	LEA + Staging**	FGR	25% Load Reduction
Tangential	Gas	100-350	37	24-72	67	
Tangential	Oil	100-350 (600)	28	20-55	10-40	Typical NO_x reductions for boilers with a 25% load reduction are:
Tangential	Coal	300-600	27-49	24-59	-	
Front Wall	Gas	130-700 (1500)	15-23	23-72	-	
Front Wall	Oil	250-550 (650)	19-35	26-45	31-46	
Front Wall	Coal	425-850	11-29	34-53	-	Gas: 30%
Horizontally Opposed	Gas	400-950 (1500)	15-21	34-71	-	Oil: 10% Coal: 18%
Horizontally Opposed	Oil	200-500	3-9	19-40	-	
Horizontally Opposed	Coal	400-900	21-28	34-48	-	
Cyclone	Oil	300-500	10-16	-	-	
Cyclone	Coal	500-1200	-	-	-	

---

*ppm @ 3% O_2, dry basis

**Variations of staged combustion. Includes two-stage, off-stoichiometric firing and/or biased firing.

Table D-6. Summary of Combustion Modification Techniques for Large Boilers

Technique	Principle of Operation	Emission Rates (NO_x)[1] NO_2 basis @ 3% O_2[2]	Limitations	Existing Applications	Applications Planned for Next 5 Years
Staged combustion with tangential firing	Lower nozzles operated fuel rich yielding reduced O_2 level in primary zone and suppression of thermal and and fuel NO_x	Gas: 100-150 ppm Oil: 125-225 ppm Coal: 200-300 ppm	Fouling of convective section; poor primary stage ignition; soot formation; possible load reduction	Retrofit of utility boilers, large industrial boilers	Inclusion of overfire air ports in new unit design
Staged combustion with wall firing	Biased burner firing or oversize air ports reduces O_2 level in primary flame zone and suppresses thermal and fuel NO_x	Gas: 200-300 ppm Oil: 250-350 ppm Coal: 350-450 ppm	Corrosion with coal firing, fouling of convective section, boiler	Retrofit of utility boilers, large industrial boilers	Inclusion of overfire air ports in new unit design
Flue gas recirculation	Recycled flue gas reduces primary flame temperature and suppresses thermal NO_x	Gas: 80-120 ppm (tangential) 250-350 ppm (wall firing) Oil: 150-220 ppm (tangential) 250-350 ppm (wall firing)	Reduced effect with coal, heavy oils; flame instability	Retrofit of gas and distillate oil utility boilers	Inclusion in design of large industrial boilers
Low excess air firing	NO_x control through reduced O_2 level in primary flame zone	Gas: 200-250 ppm (tangential) 300-350 (wall firing) Oil: 200-250 (tangential) 300-350 (wall firing) Coal: 350-450 (tangential) 450-600 (wall firing)	Unburned hydrocarbons, CO emissions at low levels of excess air; increased fouling	Routine use in utility boilers; limited use in industrial boilers	Application to commercial and industrial boilers as part of energy conservation programs

[1] Combined modifications are excluded; the NO_x control with combined modifications is generally less than the additive effects of the modifications applied singly.

[2] Emission rates cited are nominal values for average unit capacity and operating conditions; the range of available data is much wider than the values reported.

Table D-6. (continued)

Technique	Principle of Operation	Emission Rates (NO_x) NO_2 Basis @ 3% O_2^2	Limitations	Existing Applications	Applications Planned for Next 5 Years
Low air preheat	Reduced combustion air temperature yields lower flame temperature and lower NO_x	—	Reduced plant thermal efficiency	—	—
Water injection	Reduced flame temperature, possible emulsion effect	—	Reduced thermal efficiency; severe operational problems with high level of water injection	—	—
New burner designs	Controlled mixing of fuel/air yields control of thermal, fuel NO_x	Gas: 150-200 ppm Oil: 200-250 ppm Coal: 450-550 ppm	NO_x control through retrofit constrained by firebox configuration	—	Inclusion in new unit design for utility and industrial boilers

*Aerotherm Division, Acurex Corporation, "NO_x Combustion Control Methods and Costs for Stationary Sources--Summary Study", EPA-600/2-75-046, September 1975.

Table D-7. Estimated Investment Costs for Retrofitting Low Excess Air Firing to Existing Utility Boilers [7]

Unit Size	Investment Costs, $/KW	
MW	Gas & Oil	Coal
1,000	0.12	0.48
750	0.16	0.51
500	0.21	0.55
250	0.33	0.64
120	0.53	0.73

Table D-8. Major Flue Gas Treatment Plants in Japan Using Selective Catalytic Reduction [10/] (Dry Process)

Process developer	Plant owner	Plant site	Capacity (Nm^3/hr)	Source of gas	Completion
Sumitomo Chemical	Sumitomo Chiba Chem.	Sodegaura	30,000	Oil-fired boiler	July 1973
"	Higashi Nihon Methanol	"	200,000*	Heating furnace	May.1974
"	Nihon Ammonia	"	250,000*	"	March 1975
"	Sumitomo Chemical	Anegasaki	100,000*	Gas-fired boiler	Feb. 1975
"	"	"	200,000*	"	"
"	"	Niihama	200,000*	Heating furnace	March 1975
"	"	Sodegaura	250,000	Oil-fired boiler	May 1976
"	"	"	300,000	"	"
Hitachi Shipbuilding	Kansai Oil	Sakai	5,000	"	Nov. 1973
"	Idemitsu Kosan	Chiba	350,000	CO-fired boiler	Nov. 1975
"	Shindaikyowa Pet. Chem.	Yokkaichi	440,000	Oil-fired boiler	Nov. 1975
Tokyo Electric-Mitsubishi H.I.	Tokyo Electric	Minamiyokohama	10,000*	Gas-fired boiler	Jan. 1974
Kurabo	Kurabo	Hirakata	5,000	Oil-fired boiler	Nov. 1973
"	"	"	30,000	"	Aug. 1975
Kansai Electric-Hitachi Ltd.	Kansai Electric	Sakaiminato	4,000	"	Jan. 1975
Chubu-IHI-Mitsui Toatsu	Chubu Electric	Shinnagoya	8,000	"	Oct. 1974
Chubu-MKK	Chubu Electric	Yokkaichi	100	"	Oct. 1974
Mitsubishi H.I.	Mitsubishi H.I.	Hiroshima	4,000	"	Dec. 1974
Kobe Steel	Kobe Steel	Kakogawa	600	Sintering plant	May 1974

* Clean gas; those without asterisk are for dirty gas.

Table D-9. Major Flue Gas Treatment Plants in Japan Using Wet Scrubbing [10/]

Process developer	Type of process	Plant owner	Plant site	Capacity Nm³/hr	Source of gas	Completion	By-produc
(Sumitomo Metal Fuji Kasui)	Redox	Sumitomo Metal	Amagasaki	62,000	Boiler[a)]	Dec. 73	($NaNO_3$, NaC Na_2SO_4
"	"	Toshin Steel	Fuji	100,000	Furnace[d)]	Dec. 74	"
"	"	"	Osaka	39,000	Boiler[a)]	Dec. 74	"
Chiyoda	"	Chiyoda	Kawasaki	1,000	"	1973	(Gypsum $Ca(NO_3)_2$)
(Tokyo Electric Mitsubishi H.I.)	(Oxidation absorption)	Tokyo Electric	Minami-Yokohama	2,000	Boiler[b)]	Dec. 73	HNO_3
"	"	"	"	100,000	"	Oct. 74	"
(Mitsubishi Metal MKK, Nihon Chem.)	(Absorption oxidation)	Mitsubishi Metal	Omiya	4,000	Boiler[a)]	Dec. 74	KNO_3
(Fed. of Electric Power Ind. Kureha Chemical)	Reduction	Kureha Chem.	Nishiki	5,000	Boiler[a)]	Apr. 75	(Na_2SO_4 N_2)
(Fed. of Electric Power Ind. Kawasaki H.I.)	(Magnesium scrubbing)	EPDC	Takehara	5,000	Boiler[c)]	Dec. 75	(Gypsum $Ca(NO_3)_2$)
Kobe Steel	Redox	Kobe Steel	Kakogawa	1,000	Furnace[e)]	Dec. 73	(Gypsum N_2)
Chisso Corp.	Reduction	Chisso Pet. Chem.	Goi	300	Boiler[a)]	1974	$(NH_4)_2SO_4$

a) Oil-fired boiler b) Gas-fired boiler c) Coal-fired boiler

d) Metal heating furnace e) Iron ore sintering furnace

Table D-10.

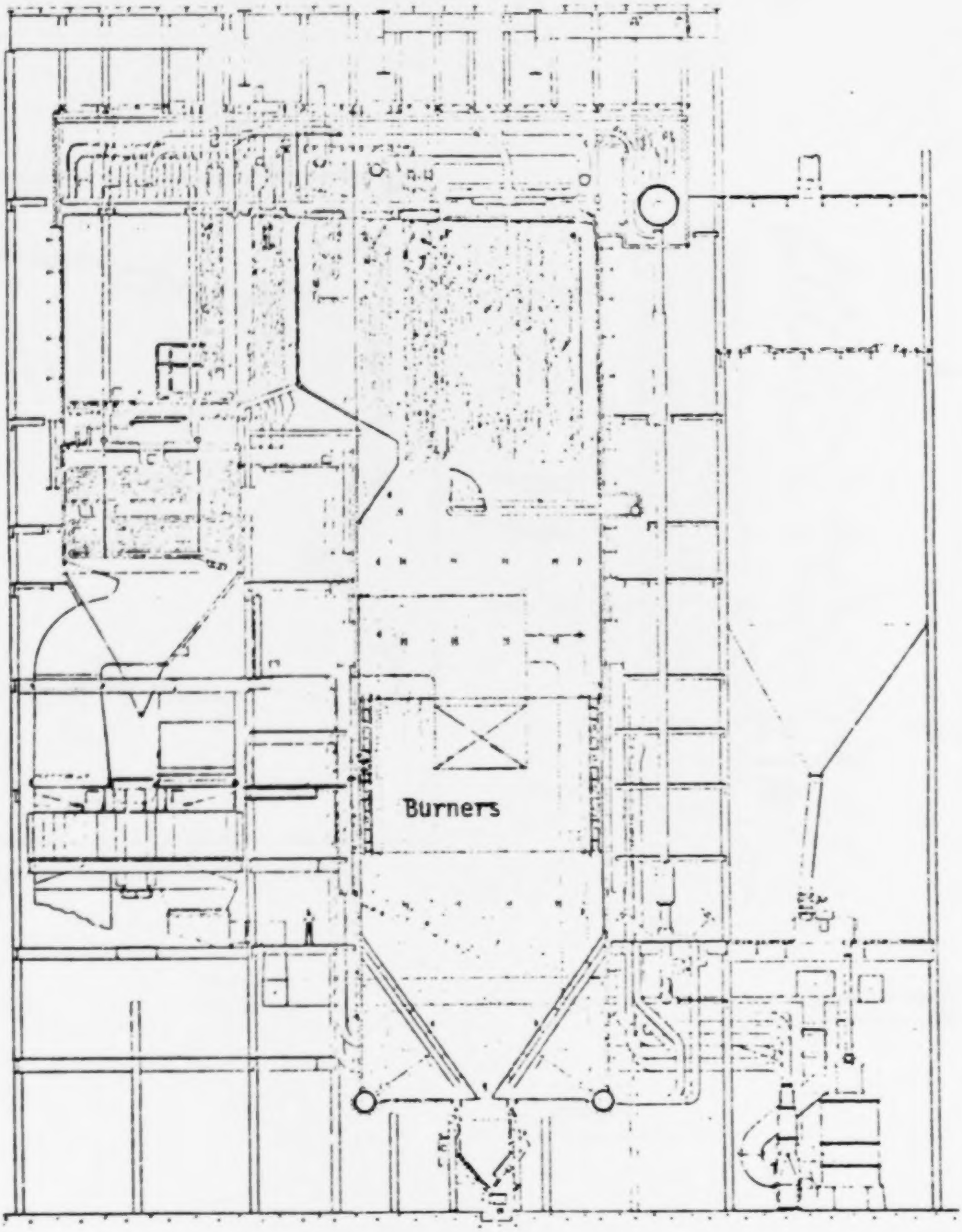
EFFECTIVENESS OF COMBUSTION MODIFICATION ON GAS TURBINES[7, 15]

Combustion Modification	Emissions			
	NO_x	CO	HC	Smoke
Interim				
Primary Zone Leaning	10 - 30% reduction	Small reduction	Small reduction	Reduction
Exhaust Gas Recirculation	~30% reduction	Negligible effect	Negligible effect	Negligible effect
Water/Steam Injection	50 - 75% reduction (oil) 60 - 90% reduction (gas)	Some reduction or increase	Small reduction or small increase	Small increase possible
Advanced Combustors				
Premixed, prevaporized, well stirred, variable geometry, external combustors	20 ppm* achievable	40 ppm achievable	5 ppm achievable	Invisible

*Prototype unit; catalytic combustor may be able to achieve 5.0 ppm NO_x.

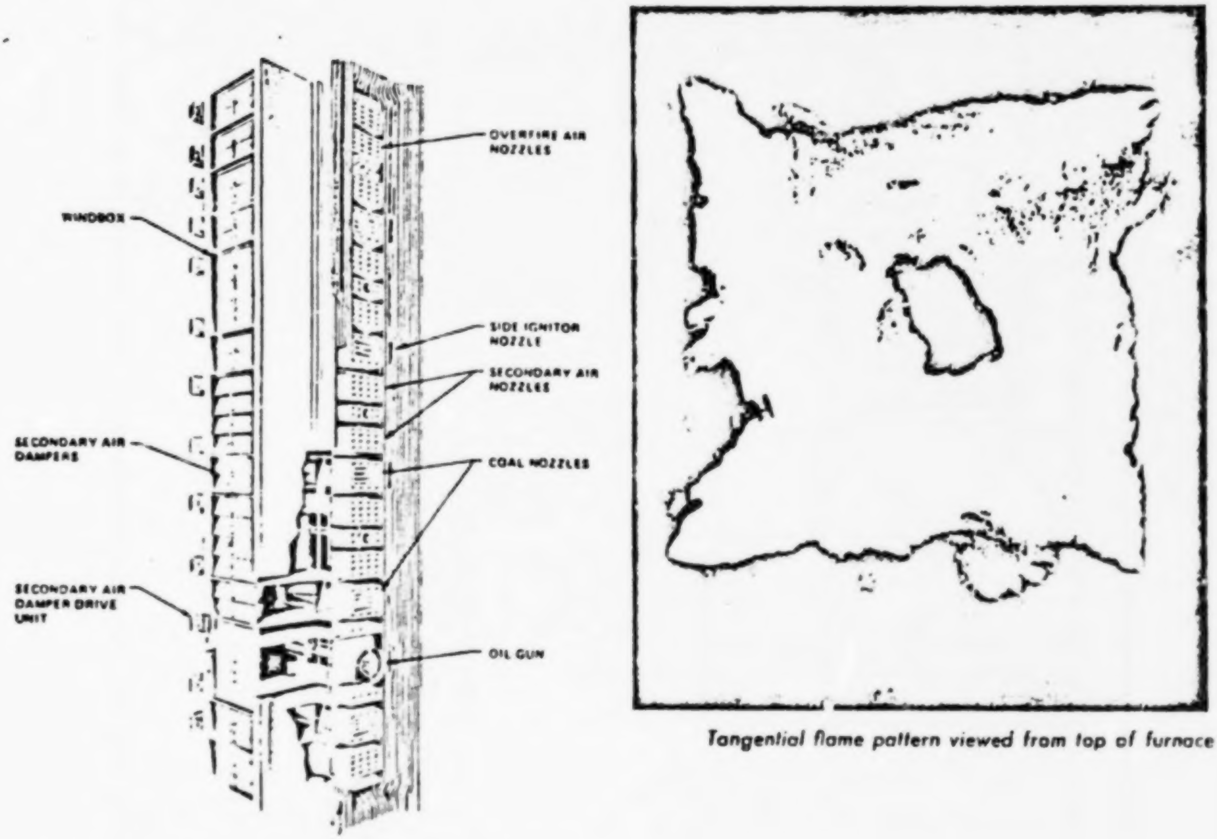
Figure D-1.

Tangentially Fired Boiler



DRAWING FURNISHED THROUGH THE COURTESY OF
COMBUSTION ENGINEERING, INC.

Reproduced from best available copy.


OVERFIRE AIR NOZZLES
WINDBOX
SIDE IGNITOR NOZZLE
SECONDARY AIR NOZZLES
SECONDARY AIR DAMPERS
COAL NOZZLES
SECONDARY AIR DAMPER DRIVE UNIT
OIL GUN

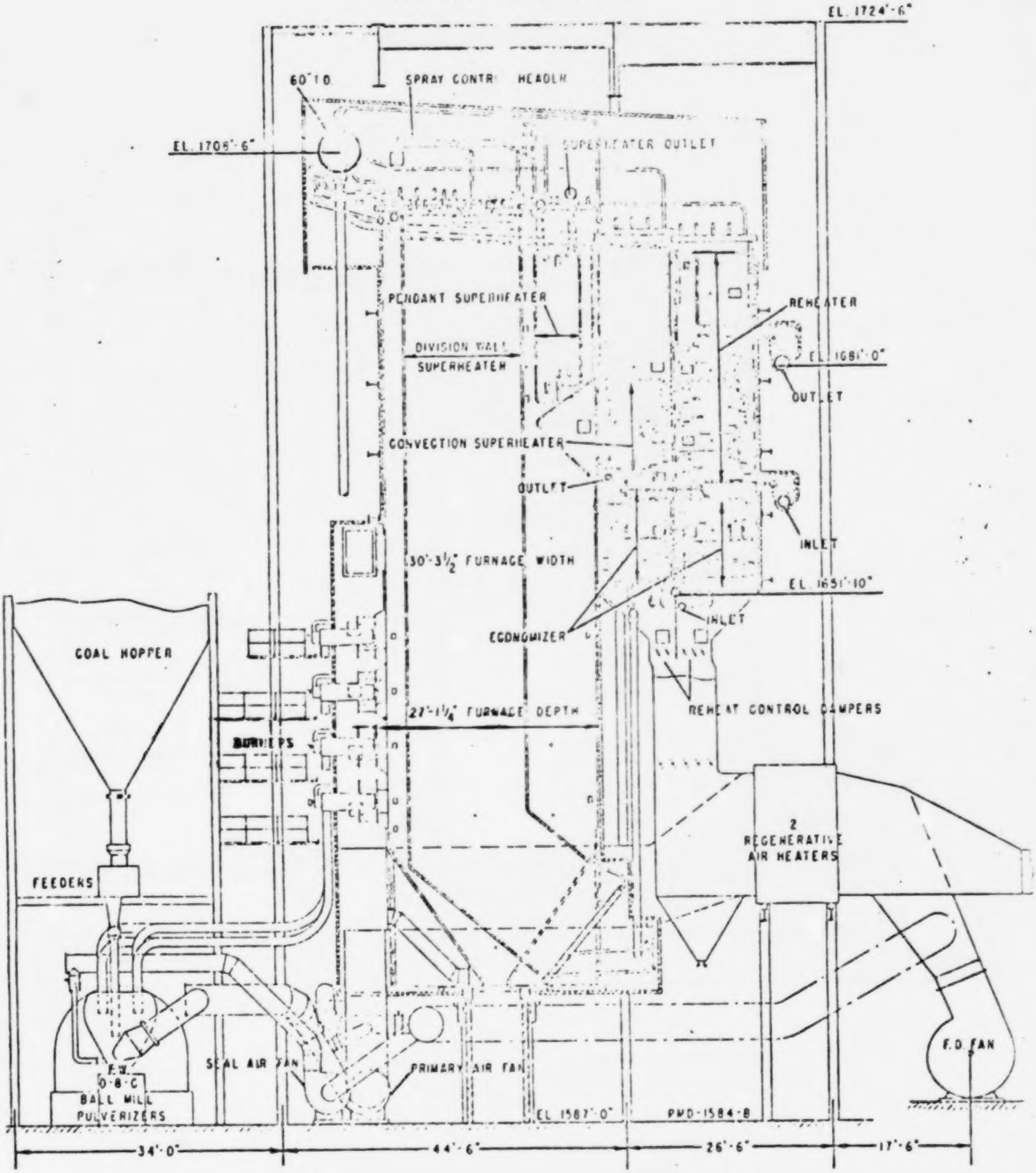
Tangential firing system incorporating overfire air for NO$_x$ control — coal firing

Tangential flame pattern viewed from top of furnace

Figure 1a.

Figure D-2.

Front Wall Fired Boiler

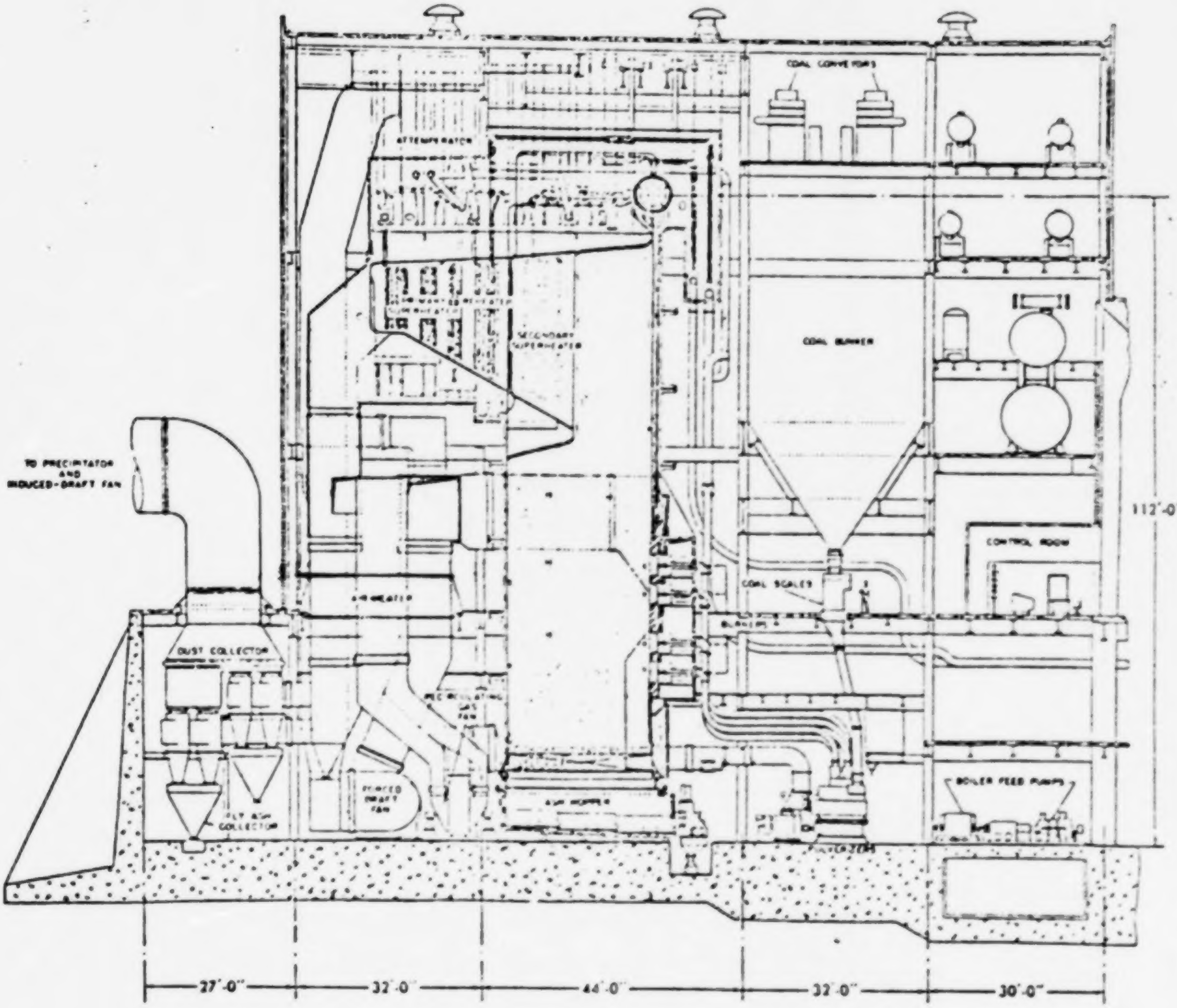

EL. 1724'-6"
60" I.D.
SPRAY CONTR. HEADER
EL. 1706'-6"
SUPERHEATER OUTLET
PENDANT SUPERHEATER
REHEATER
DIVISION WALL SUPERHEATER
EL. 1681'-0"
OUTLET
CONVECTION SUPERHEATER
OUTLET
INLET
30'-3½" FURNACE WIDTH
EL. 1651'-10"
INLET
ECONOMIZER
COAL HOPPER
REHEAT CONTROL DAMPERS
27'-1¼" FURNACE DEPTH
BURNERS
2 REGENERATIVE AIR HEATERS
FEEDERS
F.D. FAN
SEAL AIR FAN
PRIMARY AIR FAN
F.W. D-B-C BALL MILL PULVERIZERS
EL. 1587'-0"
PMD-1584-B
34'-0"
44'-6"
26'-6"
17'-6"

DRAWING FURNISHED THROUGH THE COURTESY OF THE FOSTER WHEELER CORPORATION

Reproduced from best available copy.

Figure D-3.

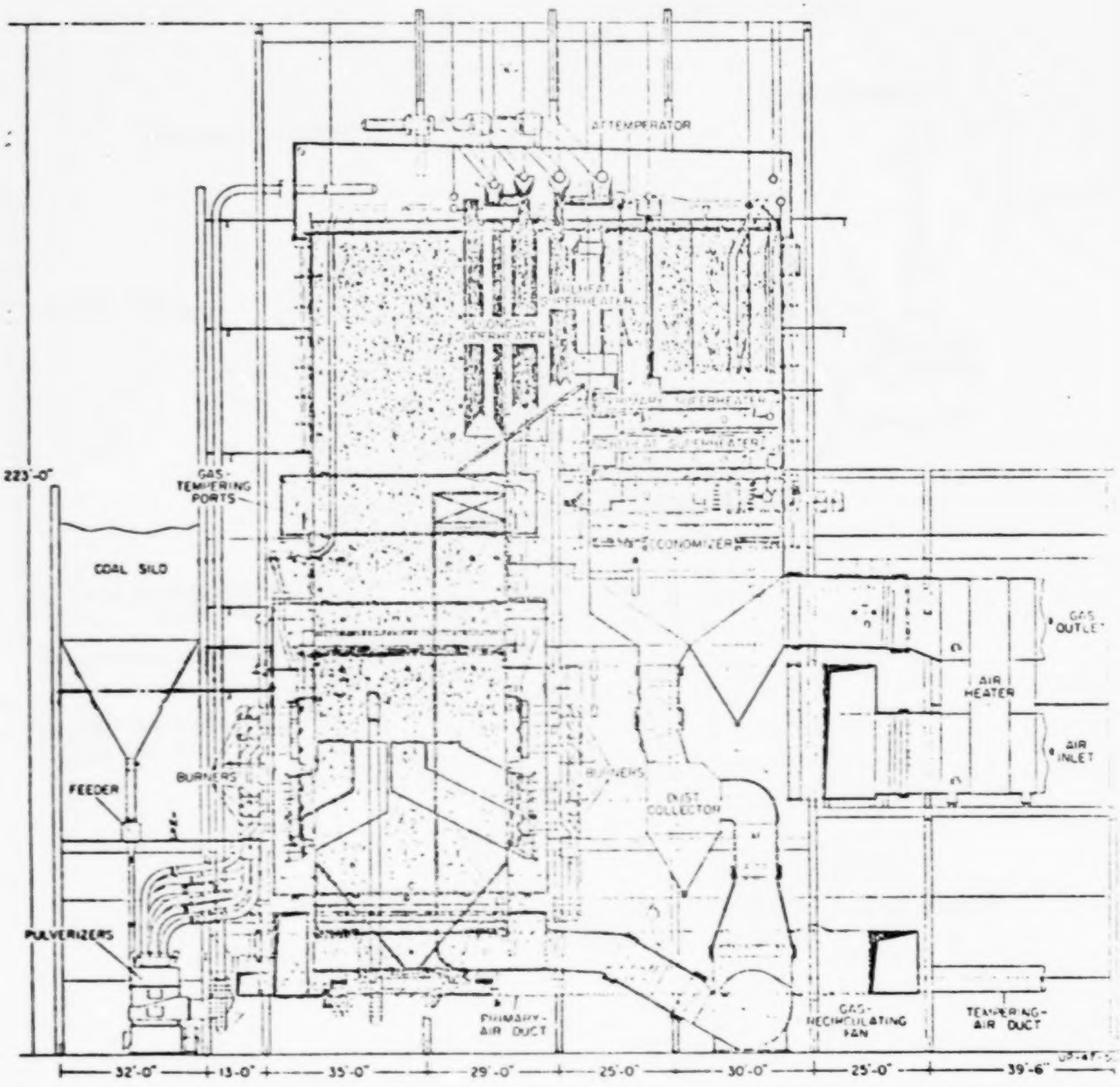
Front Wall Fired Boiler


COAL CONVEYORS
ATTEMPERATOR
REHEATER
PRIMARY SUPERHEATER
SECONDARY SUPERHEATER
COAL BUNKER
TO PRECIPITATOR AND INDUCED-DRAFT FAN
AIR HEATER
112'-0"
CONTROL ROOM
COAL SCALES
BURNERS
DUST COLLECTOR
RECIRCULATING GAS FAN
FORCED DRAFT FAN
ASH HOPPER
FLY ASH COLLECTOR
BOILER FEED PUMPS
PULVERIZERS
27'-0"
32'-0"
44'-0"
32'-0"
30'-0"

DRAWING FURNISHED THROUGH THE COURTESY OF
THE BABCOCK AND WILCOX COMPANY

Figure D-4.

Horizontally Opposed Fired Boiler


ATTEMPERATOR
SECONDARY SUPERHEATER
REHEAT SUPERHEATER
PRIMARY SUPERHEATER
ECONOMIZER
223'-0"
GAS-TEMPERING PORTS
COAL SILO
FEEDER
BURNERS
BURNERS
PULVERIZERS
DUST COLLECTOR
GAS OUTLET
AIR HEATER
AIR INLET
PRIMARY-AIR DUCT
GAS-RECIRCULATING FAN
TEMPERING-AIR DUCT
32'-0"
13-0"
35'-0"
29'-0"
25'-0"
30'-0"
25'-0"
39'-6"

DRAWING FURNISHED THROUGH THE COURTESY OF THE BABCOCK AND WILCOX COMPANY

Reproduced from best available copy.

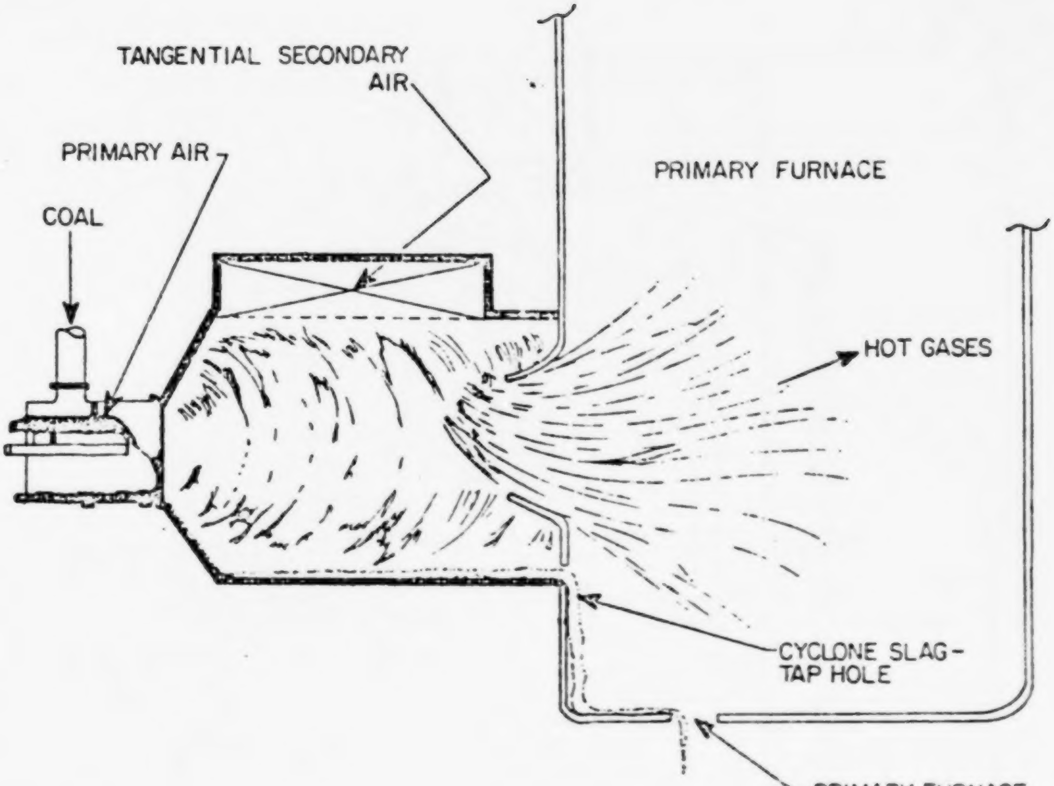
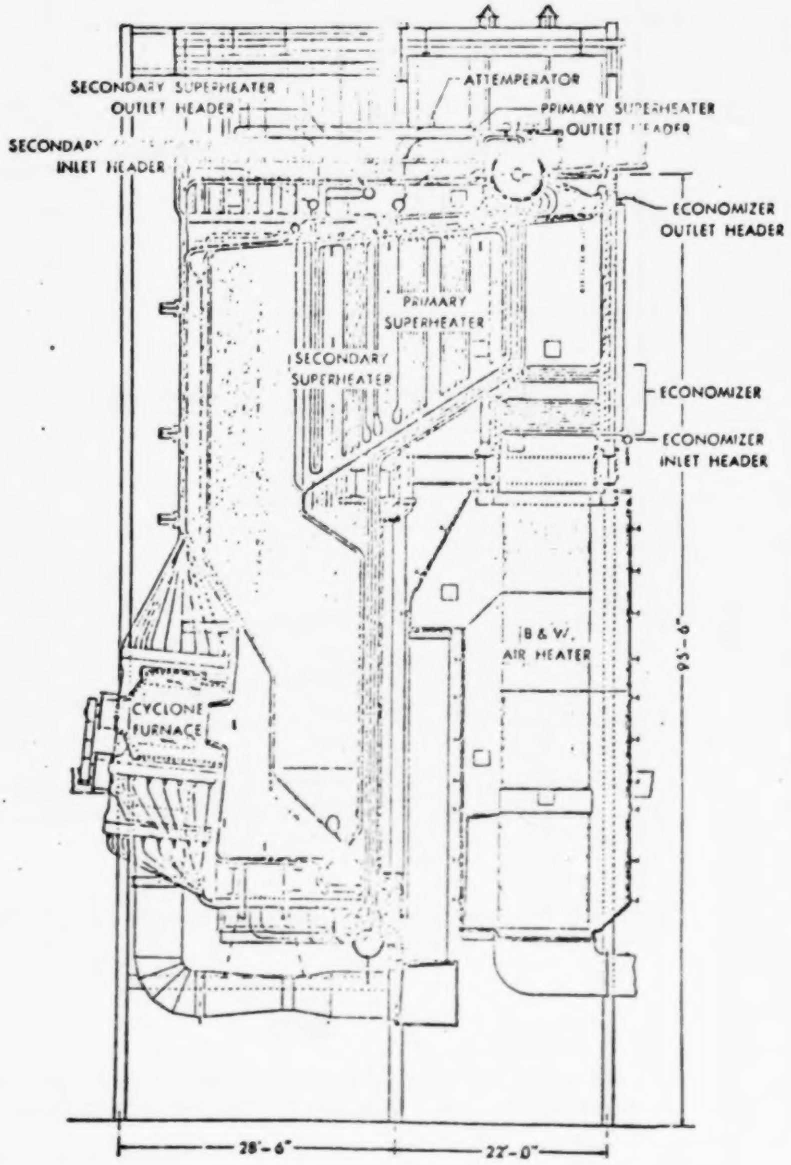

TANGENTIAL SECONDARY AIR
PRIMARY AIR
COAL
PRIMARY FURNACE
HOT GASES
CYCLONE SLAG-TAP HOLE
PRIMARY FURNACE SLAG-TAP HOLE

Figure D-5. Schematic drawing of cyclone furnace. Usually several cyclones are used on a single primary furnace.

Figure D-6.

Cyclone Fired Boiler


SECONDARY SUPERHEATER OUTLET HEADER
ATTEMPERATOR
PRIMARY SUPERHEATER OUTLET HEADER
SECONDARY SUPERHEATER INLET HEADER
ECONOMIZER OUTLET HEADER
PRIMARY SUPERHEATER
SECONDARY SUPERHEATER
ECONOMIZER
ECONOMIZER INLET HEADER
B & W. AIR HEATER
CYCLONE FURNACE
95'-6"
28'-6"
22'-0"

DRAWING FURNISHED THROUGH THE COURTESY
OF THE BABCOCK & WILCOX COMPANY

Reproduced from best available copy.

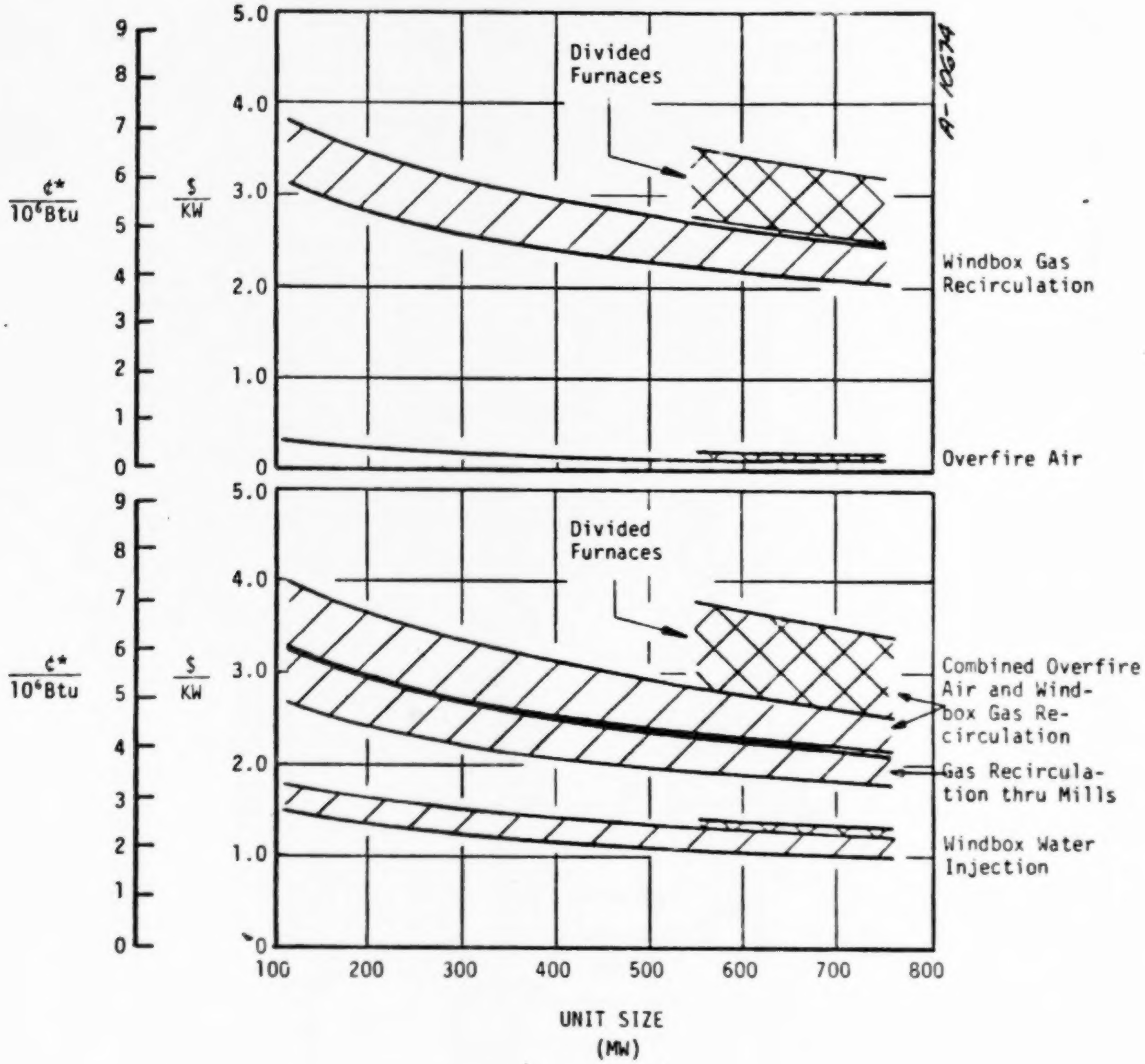


Figure D-7. 1973 installed equipment costs of NO_x control methods for new tangentially, coal-fired units (included in initial design).*

*Based on: 5400 hrs/yr at rated MW and net plant heat rate of 10^4 Btu/KWhr (Reference 4-3).

*Aerotherm Division, Acurex Corporation, "NO_x Combustion Control Methods and Costs for Stationary Sources--Summary Study", EPA-600/2-75-046, September 1975.

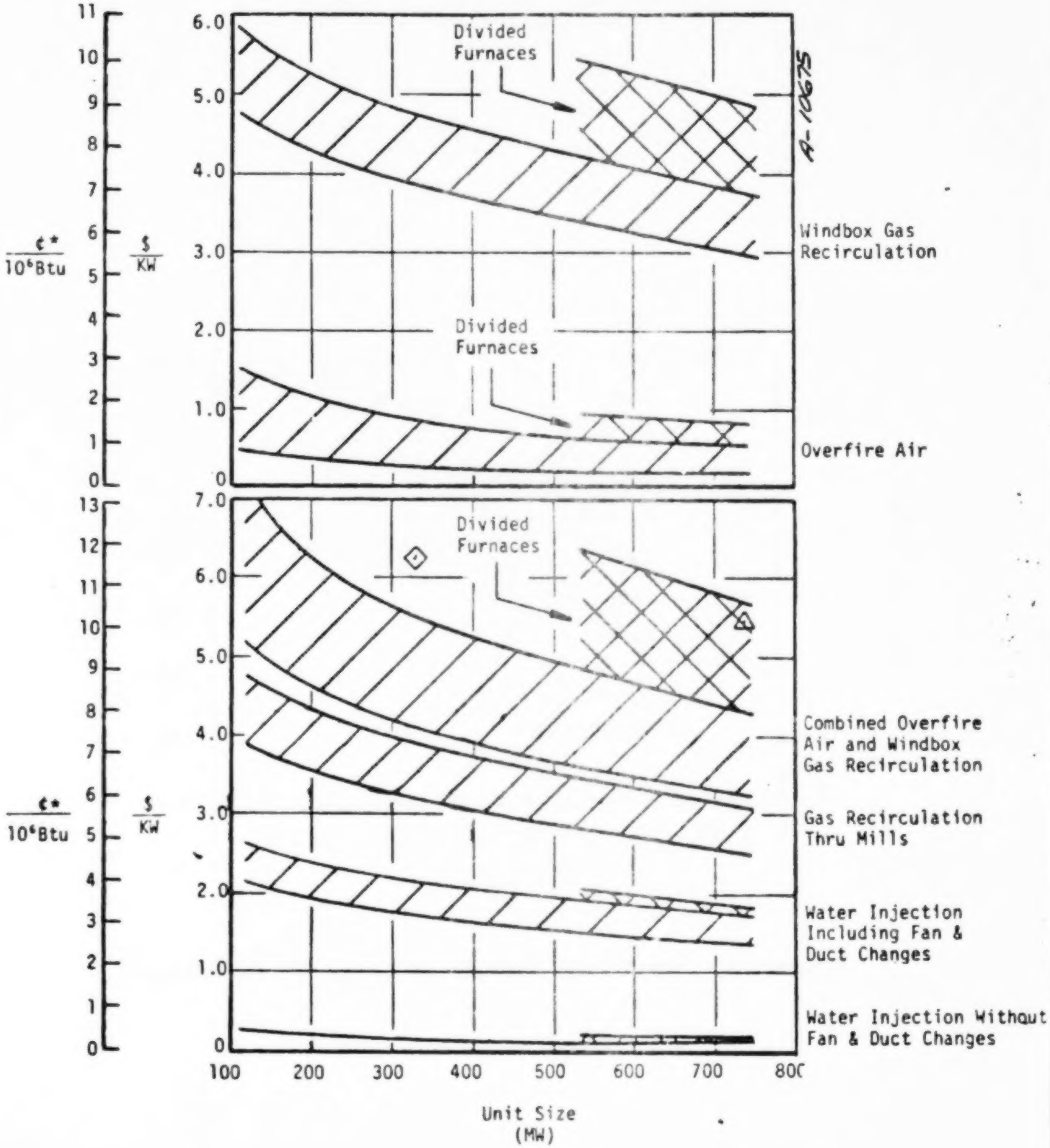


Figure D-8. 1973 installed equipment costs of NO$_x$ control methods for existing tangentially, coal-fired units (heating surface changes not included).*

△ PG&E Portrero #3 *Based on 5400 hrs/yr at rated MW and net plant heat rate of 10^4 Btu/kwhr
◇ PG&E Pittsburg #7 (Reference 4-2).

*Aerotherm Division, Acurex Corporation, "NO$_x$ Combustion Control Methods and Costs for Stationary Sources--Summary Study", EPA-600/2=75-046, September 1975.

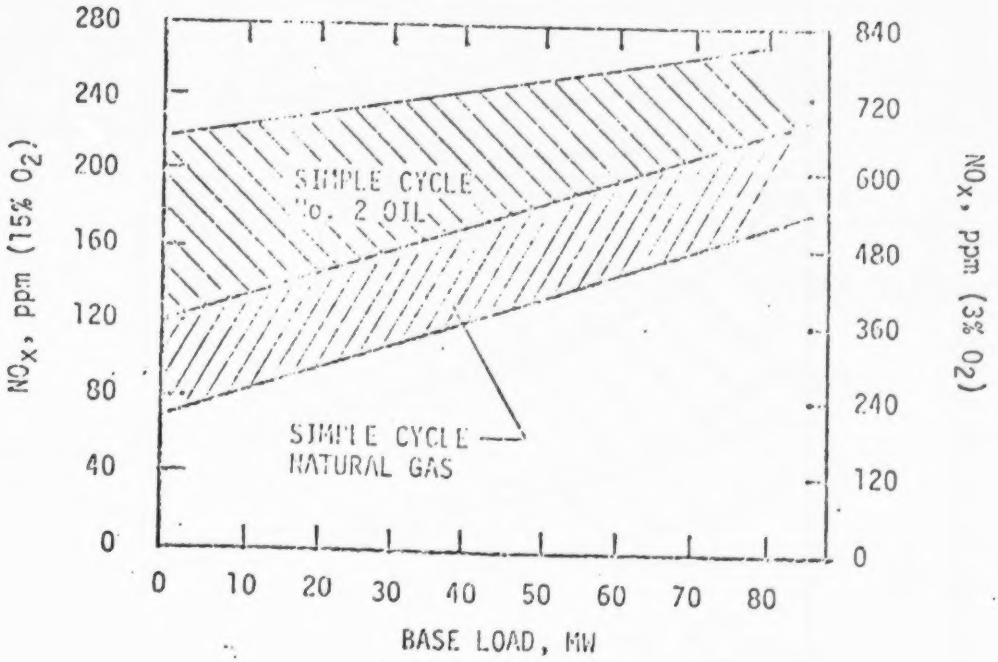


Figure D-9. Typical Gas Turbine Base Load NO$_x$ Emissions[7/]

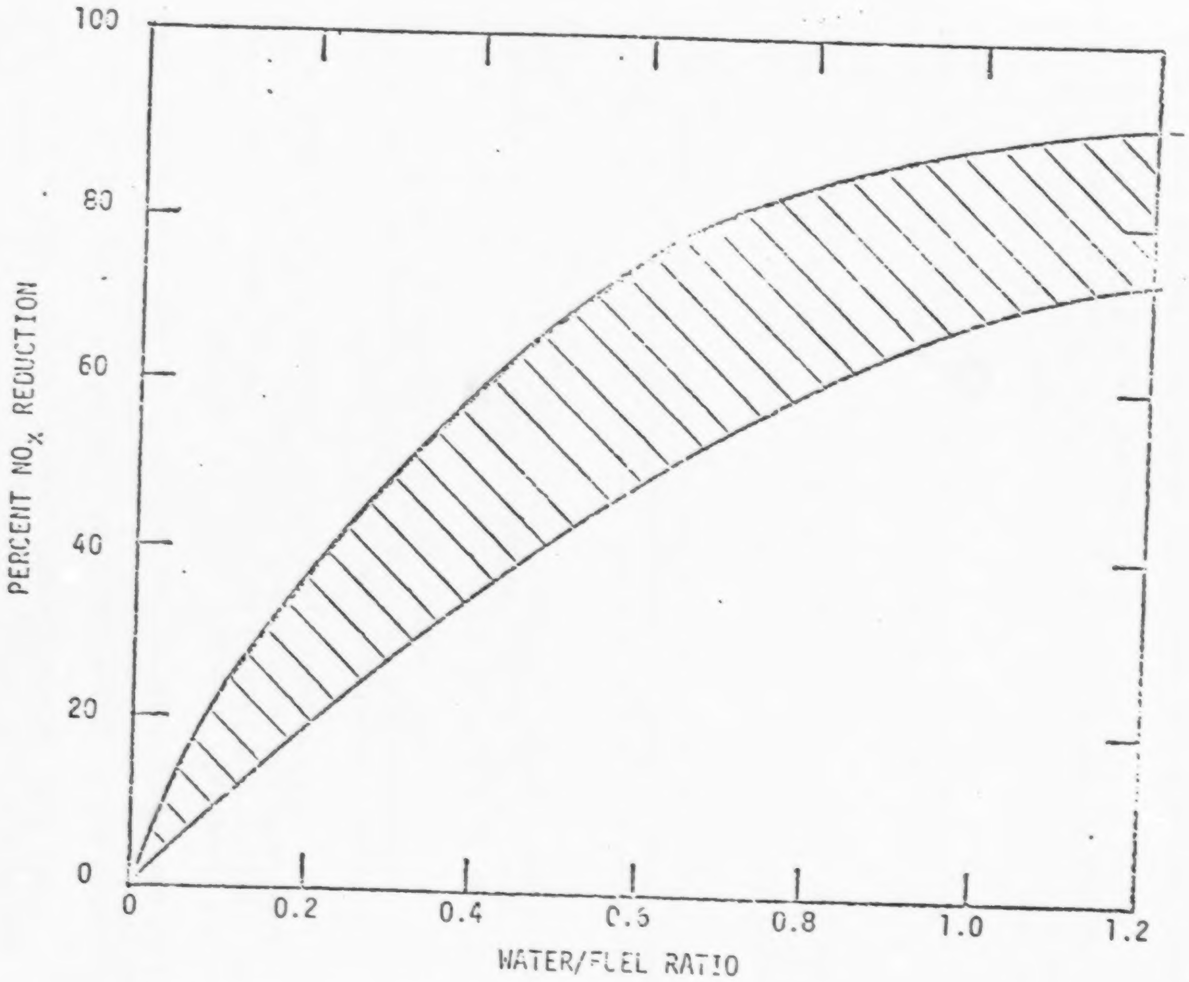


Figure D-10. Effectiveness of Water or Steam Injection in Reducing NO_x Formation[7]

References

1. Shaw, J. T., and A. T. Thomas, NTIS No. PB 229-102/AS, "Oxides of Nitrogen in Relation to Combustion of Coal", 7th International Conference on Coal Science, Prague, Czechoslovakia, June 1968.

2. Martin, G. B., and E. E. Berkau, "An Investigation of the Conversion of Various Fuel Nitrogen Compounds to Nitrogen Oxides in Oil Combustion", AIChE/Symposium Series, Air Pollution and Its Control, Volume 68 (1972).

3. Turner, D. W., R. L. Andrews, and C. W. Siegmund, "Influence of Combustion Modification and Fuel Nitrogen Content on Nitrogen Oxides Emissions from Fuel Oil Combustion", Presented at the 64th Annual AIChE Meeting, San Francisco, California, November 1971.

4. Cato, G. A., et al., "Field Testing: Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers - Phase I", EPA-650-2-74-078a, October 1974.

5. Hobelt, W. W. and B. M. Howell, "Control of NO_x Formation in Tangentially Coal-Fired Steam Generators", Presented at Electric Power Research Institute NO_x Control Technology Seminar, San Francisco, California, February 1976.

6. Brackett, C. E., and J. A. Borsen, "The Dual Register Pulverized Coal Burner - An NO_x Control Device", Presented at Electric Power Research Institute NO_x Control Technology Seminar, San Francisco, California, February 1976.

7. Bowen, Lachapelle, and Stern, "Overview of EPA's NO_x Control Technology from Stationary Sources", Control Systems Laboratory, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 4, 1974.

8. Blakeslee, C. E., and A. P. Selker, "Program for Reduction of NO_x from Tangential Coal-Fired Boilers, Phase I", EPA-650/2-73-005, August 1973.

9. Lyon R. K. and J. P. Longwell, "Selective, Non-Catalytic Reduction of NO_x with Ammonia", Exxon Research and Engineering, Presented at the Electric Power Research Institute NO_x Control Technology Seminar, San Francisco, California, February 1976.

10. Jumpei, Ando and Heiichiro Tokata, "NO_x Abatement Technology in Japan for Stationary Sources", Faculty of Science and Engineering, Chuo University, Kasuga, Bunkyo-Ku, Tokyo, Japan, March 1975.

11. Draft of Standards Support and Environmental Impact Statement for Standards of Performance--Stationary Gas Turbines, U. S. Environmental Protection Agency, OAQPS, MD-13, Research Triangle Park, North Carolina 27711, March 1975.

12. Seiffert, Randy D. and Frank Collins, "Drafts of Standards Support Document for an Investigation of the Best Systems of Emission Reduction for Stationary Internal Combustion Engines", U. S. Environmental Protection Agency, OAQPS, MD-13, Research Triangle Park, North Carolina 27711, September 1975.

13. Battelle Columbus Laboratories, "Molecular Sieve NO_x Control Process in Nitric Acid Plants", EPA-600/2-76-015, January 1976.

14. Control Techniques for Nitrogen Oxides from Stationary Sources, NAPCA Publication No. AP-67, March 1970.

15. Roessler, W. U. et al., "Assessment of the Applicability of Automotive Emission Control Technology for Stationary Engines", EPA-650.2-74-051, July 1974.

Addendum References

1. Bartok, W. et al., "Systems Study of Nitrogen Oxide Control Methods for Stationary Sources, Volume II", Prepared for the National Air Pollution Control Administration, NTIS Report No. PB 192-789, Esso, 1969.

2. Zeldovitch, Y. B., P. Y. Sadonikov, and D. A. Frank-Kamenetskii, "Oxidation of Nitrogen in Combustion", Academy of Sciences of USSR, Institute of Chemical Physics, Moscow-Leningrad, 1947.

3. Heap, M. P., T. M. Lowes, R. Walmsley, and H. Bartelds, "Burner Design Principles for Minimum NO_x Emissions", EPA Coal Combustion Seminar, Research Triangle Park, North Carolina, June 1973.

4. Pershing, D. W., G. B. Martin, and E. E. Berkau, "Influence of Design Variables on the Production of Thermal and Fuel NO from Residual Oil and Coal Combustion", Presented at the 66th Annual AIChE Meeting, Philadelphia, Pennsylvania, November 1973.

5. Hall, R. E., J. H. Wasser, and E. E. Berkau, "A Study of Air Pollutant Emissions from Residential Heating Systems", EPA-650/2-74-003, January 1974.

6. Dickerson, R. A., and A. S. Okuda, "Design of an Optimum Distillate Oil Burner for Control of Pollutant Emissions", EPA-650/2-74-047, June 1974.

7. Shoffstall, D. R. and D. H. Larson, "Aerodynamic Control of Nitrogen Oxides and Other Pollutants from Fossil Fuel Combustion", EPA-650/2-73-033a, October 1973.

8. Brown, R. A., H. B. Mason, and R. J. Schreiber, "Systems Analysis Requirements for Nitrogen Oxide Control of Stationary Sources", EPA-650/2-74-091, September 1974.

9. McGowin, C. R., "Stationary Internal Combustion Engines in the United States", EPA-R2-73-210, April 1973.

10. Bartok, W. et al., "Systematic Field Study of NO_x Emissions Control Methods for Utility Boilers", Esso Research and Engineering Company, Linden, New Jersey. Report GRU.4GNOS.71, Prepared for the Office of Air Programs, Environmental Protection Agency, Research Triangle Park, North Carolina, December 31, 1971.

11. Jain, L. K., E. L. Calvin, and R. L. Looper, "State of the Art for Controlling NO_x Emissions, Part I: Utility Boilers", Final Report, Catalytic, Inc., EPA-R2-72-072a, September 1972.

12. Berkau, E. E., and D. G. Lachapelle, "Status of EPA's Combustion Program for Control of Nitrogen Oxide Emissions from Stationary Sources", Presented at the Southeast APCA Meeting, Raleigh, North Carolina, September 19, 1972.

13. Crawford, A. R. et al., "Field Testing: Application of Combustion Modification to Control of NO_x Emissions from Utility Boilers", EPA-650/2-74-066, June 1974.

14. Levy, A. et al., "A Field Investigation of Emissions from Fuel Oil Combustion for Space Heating", Conducted by Battelle Columbus Laboratories for the American Petroleum Institute, API Publication 4099, November 1, 1971.

15. Barrett, R. E. et al., "Field Investigation of Emissions from Combustion Equipment for Space Heating", EPA-R2-73-084a, June 1973.

16. Crits, G. J., "Economic Factors in Water Treatment", Industrial Water Eng., 8(8), 22 (1971).

17. Tyco Laboratory Final Report, "Development of the Catalytic Chamber Process", EPA-R2-72-038, September 1972.

18. Esso Research Report, "Development of the Aqueous Processes for Removing NO_x from Flue Gases", EPA-R2-72-051, September 1972 and Addendum, EPA-R2-73-051a, June 1973.

SECTION E

MOTOR VEHICLES

1. NO_x Emissions

Automobiles, light-duty trucks, and heavy-duty trucks comprise the major NO_x emission categories of highway vehicles.* Within each of these categories different engine types and fuel variations result in significantly different emission characteristics. In addition, different exhaust emission standards and compliance dates apply to different vehicles. Because of these variations, highway vehicle emissions change with time and must be calculated for a specific time period, normally one calendar year. The major reasons for this time-dependence are (1) the gradual replacement of vehicles without emission control equipment by vehicles with control equipment, and (2) the gradual deterioration of vehicles with control equipment as they accumulate age and mileage. Detailed information is contained within AP-42 which will allow the reader to consider these factors in calculating motor vehicle emissions.

Other factors that influence overall motor vehicle emissions include the vehicle mix ratio (LDV, LDT, HDVG & HDVD), vehicle age distribution, average vehicle speed, ambient temperature and hot vs. cold operation. After considering these factors, as well as expected VMT growth, a composite emission factor can be developed to estimate overall motor vehicle emissions from the entire mobile emission class.

Figure E-1 presents a national composite motor vehicle (LDV, LDT, HDVG and HDVD) emission rate projected through 1995, based on the current Federal Motor Vehicle Control Program**(FMVCP). Incorporated into this

---

*Automobiles = Light Duty Vehicles = LDV
Light Duty Trucks = LDT
Heavy Duty Trucks = Heavy Duty Vehicles (Gasoline) = HDVG
Heavy Duty Vehicles (Diesel) = HDVD

**ESECA (1974)

composite motor vehicle emissions projection is a 3% annual VMT growth rate which is typical of most urban areas. As illustrated, a 14% reduction in NO_x emissions from motor vehicles is expected on a national basis during the 1975-1980 time period. Congress is reviewing the Clean Air Act and if changes are made to the present motor vehicle emission standards, associated changes will be observed in the NO_x emissions projections.

The development of accurate VMT growth projections to be incorporated into the composite emission rate projections is paramount. Growth factors over a 10-year or longer period are very significant and are one of the principal factors influencing the overall effectiveness of motor vehicle control program. Figure E-2 illustrates various growth factors associated with different annual growth rates (0.5% to 4.0% per year). As shown by Figure E-2, automotive VMT growth factors are extremely sensitive to the change in growth rates. Therefore, it is desirable to accurately determine the expected areawide VMT growth for the area under study and, if necessary, to correct Figure E-1 FMVCP projections from a 3% annual VMT growth to the applicable growth rate. The correction factor can be developed by dividing the applicable growth factor by the 3% growth factor.

Another important factor which influences the composite emission projection is the vehicle age distribution for an area. Similar to VMT growth information, locally specific information on motor vehicle age distribution should be obtained if needed. Figure E-3 illustrates how vehicle use varies with vehicle age and presents (1) a national age distribution and (2) an age distribution for Detroit. As illustrated in Figure E-3, there is a much higher percentage of newer in-use motor vehicles (less than 3 years old) in Detroit than are in use on a national basis. Because auto use patterns are associated with the auto replacement rate, the total effect of an auto emission standard is not fully achieved until 5 to 10 years after a standard is implemented. In areas such as Detroit, the high motor vehicle replacement rate will tend to result in a more rapid reduction in composite NO_x emissions than predicted nationally. However, in areas with lower replacement rates, NO_x reductions may be achieved later than predicted nationally. On a national basis less than 15% of the in-use vehicles are of the current model year and less than 50 percent were manufactured in the last five years. In addition to the slow auto replacement rate, motor vehicle emissions typically increase as an automobile gets older (2% per year for pre-1975 vehicles for first 10 years) which also tends to reduce the immediate impact of motor vehicle emission standards.

Another important factor influencing overall composite NO_x emission factors is the motor vehicle mix ratio. More specifically, this factor represents the ratio of LDV:LDT:HDVG:HDVD . The mix ratio is important because (1) it represents the weighting factors for the different motor vehicle emission categories which have significantly different NO_x emission rates and (2) it can vary greatly from area to area.

Figure E-4 illustrates the projected composite NO_x emission factors for the four major motor vehicle classes based on the FMVCP considering standard conditions and considering emission control equipment deterioration. As illustrated, on a per vehicle basis, the NO_x emissions from HDVG or HDVD are significantly greater than LDV emissions. However, as illustrated in Figure E-5, the much greater total VMT for LDV results in LDV's having the major impact on NO_x emissions in urban areas.

2. Composite Emission Factors

The development of composite emission factors is discussed in greater detail in AP-42 but the procedure is based on weighted averaging of emission factors for in-use vehicles for the year of interest.

Listed below in the basic summation equation which is used to develop composite emission factors:

$$e_{npstw} = \sum_{i=n-12}^{n} c_{ipn}\, m_{in}\, v_{ips}\, z_{ipt}\, r_{iptw}$$

where: e_{npstw} = Composite emission factor in g/mi (g/km) for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), and percentage cold operation (w)

c_{ipn} = The FTP (1975 Federal Test Procedure) mean emission factor for the i^{th} model year vehicles during calendar year (n) and for pollutant (p)

m_{in} = The fraction of annual travel by the i^{th} model year vehicles during calendar year (n)

v_{ips} = The speed correction factor for the i^{th} model year vehicles for pollutant (p) and average speed (s)

z_{ipt} = The temperature correction factor for the i^{th} model year vehicles for pollutant (p) and ambient temperature (t)

r_{iptw} = The hot/cold vehicle operation correction factor for the i^{th} model year vehicle for pollutant (p), ambient temperature (t), and percentage cold operation (w)

A review of this composite emission factor (e_{npstw}) summation equation indicates the vehicle emission factor (c_{ipn}) is weighted by a VMT use factor (m_{in}) and corrected for speed (v_{ips}), ambient temperature (z_{ipt}) and percent hot/cold operation (r_{iptw}) if nonstandard contitions exist. Standard conditions are: for temperature, 68^{O}F - 86^{O}F, nominally 75^{O}F; for speed, 19.6 mph; for hot/cold ratio, 20% cold operation.

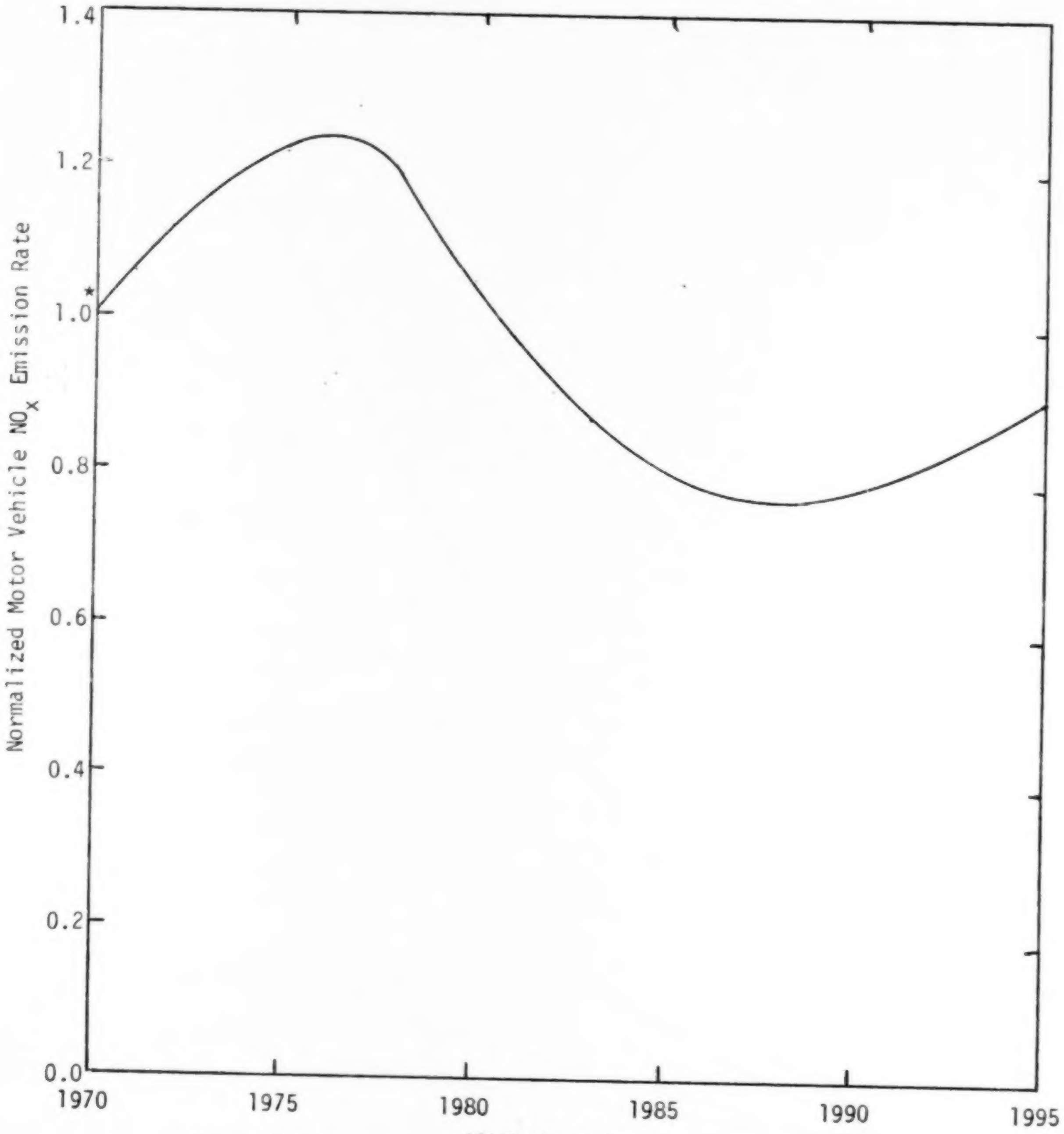
The temperature correction factors are available over a range of 20^oF-80^oF; the speed correction factors are in two parts, the "normal" speed correction from 15-45 mph, and the "low speed" corrections for 5 and 10 mph; the hot/cold correction factor is usable from 0-100% cold operation (it should be pointed out that, for cars after 1975 equipped with catalysts, the hot/cold correction includes another factor, hot start percentage, to account for the variation in emissions from catalyst equipped vehicles that have had less than 1 hour to cool before being restarted). All of the above correction factors are discussed in more detail in AP-42.

In general the above correction factors will effect projected NO_x emissions to a lesser extent than growth factors. For example, most operational correction factors effect NO_x emissions by less than 20% whereas the difference between a 2% and 3% annual growth rate over a twenty year period will make a 30% difference in NO_x emission projections. Because of the different relative importance of the various factors, they should be considered on a priority basis starting with the factor which will effect NO_x emission calculations the most.

In relation to the specific operational correction factor, Figures E-6, 7, and 8 present speed correction factors (V_{ips}). As illustrated NO_x emissions increase both as average vehicle speed is increased or decreased from standard conditions (19.6 mph). The ambient temperature correction (Z_{ipt}) factor (Figure E-9) increases as the ambient temperature is reduced from standard conditions (75^0F). The final correction factor, the hot/cold operational factor (r_{iptw}) is a function of two variables (see Figure E-10). The first variable is percent cold operations (w). The NO_x correction factor reduces with increased cold operation. The second variable is ambient temperature which also causes the hot/cold correction factor to be reduced at lower temperatures. In summary, the NO_x emission rate for motor vehicles is maximized at high speeds, low ambient temperature, and steady state conditions and minimized at medium speed, high ambient temperatures and short-term operations.

FIGURE E-1

NORMALIZED MOTOR VEHICLE EMISSIONS RATE



Assumptions:

1. National average automobile and truck age distribution
2. Low altitude, standard conditions
3. 3% Compounded (annual) growth rate
4. National average vehicle mix (LDV 80.4%; LDT 11.8%; HDG 4.6%; HDD 3.2
5. 1970 composite emission factor 4.6 g/mi

FIGURE E-2

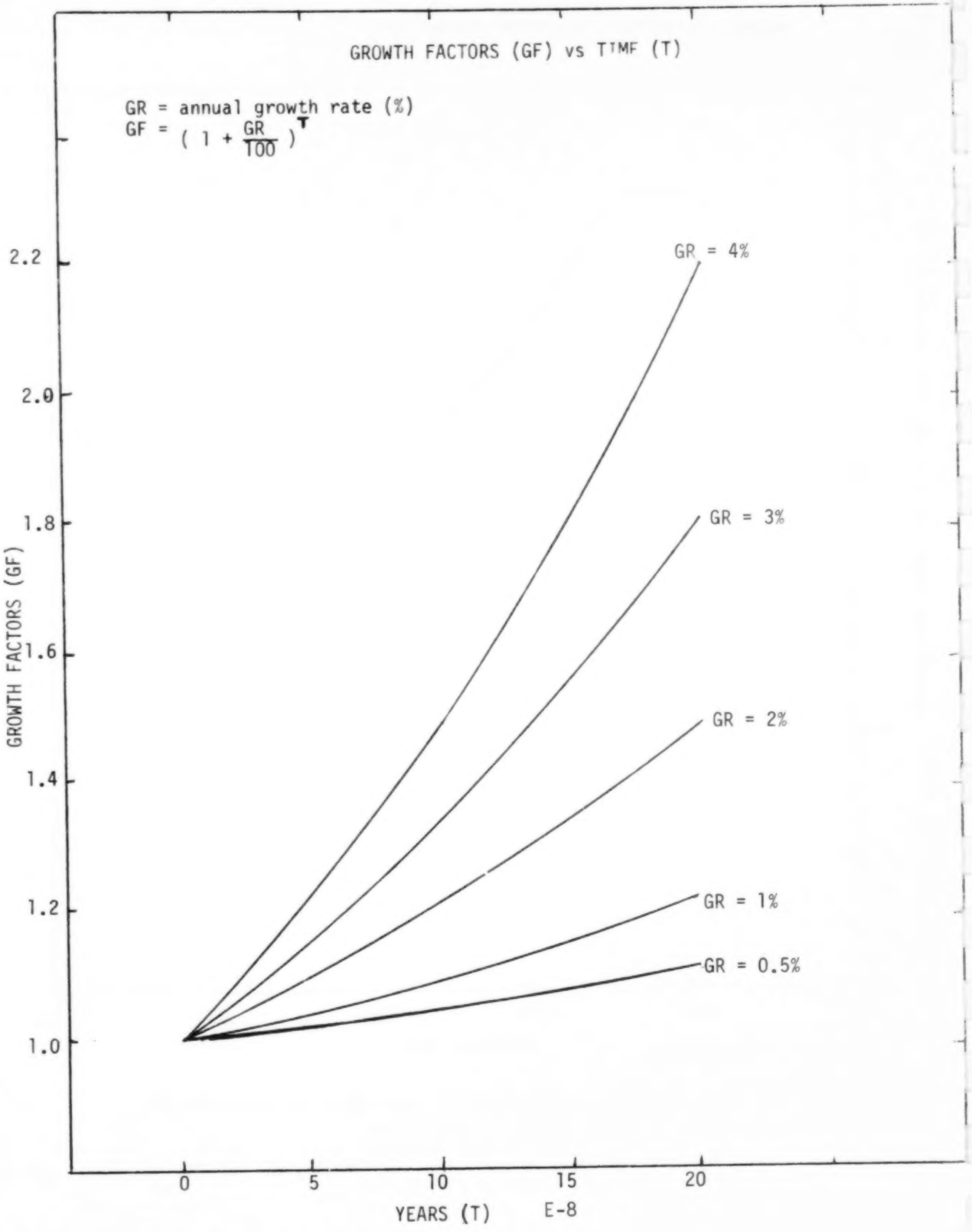
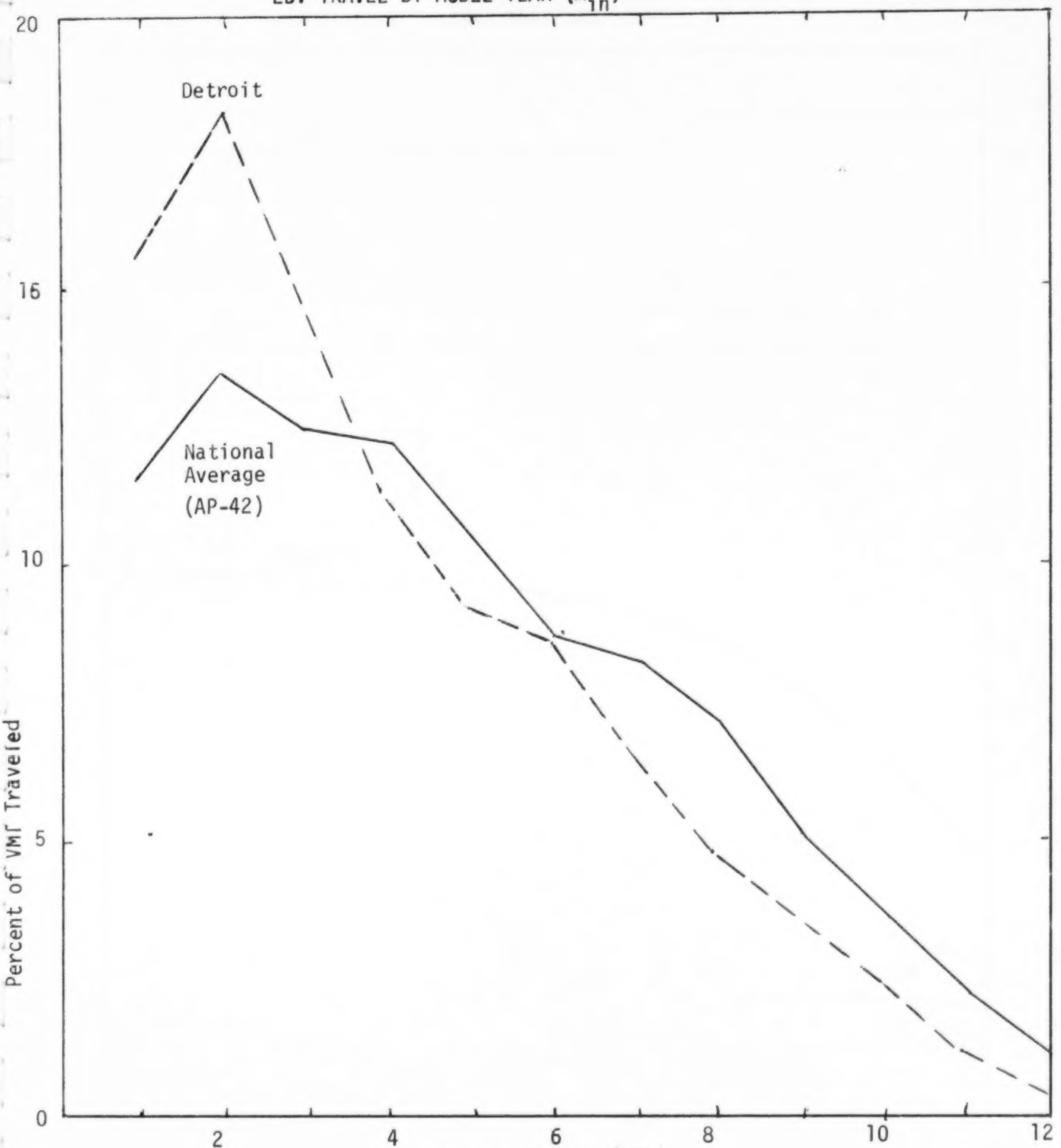

GROWTH FACTORS (GF) vs TIME (T)
GR = annual growth rate (%)
GF = $\left(1 + \frac{GR}{100}\right)^{T}$
GR = 4%
GR = 3%
GR = 2%
GR = 1%
GR = 0.5%
GROWTH FACTORS (GF)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0
5
10
15
20
YEARS (T)

FIGURE E-3

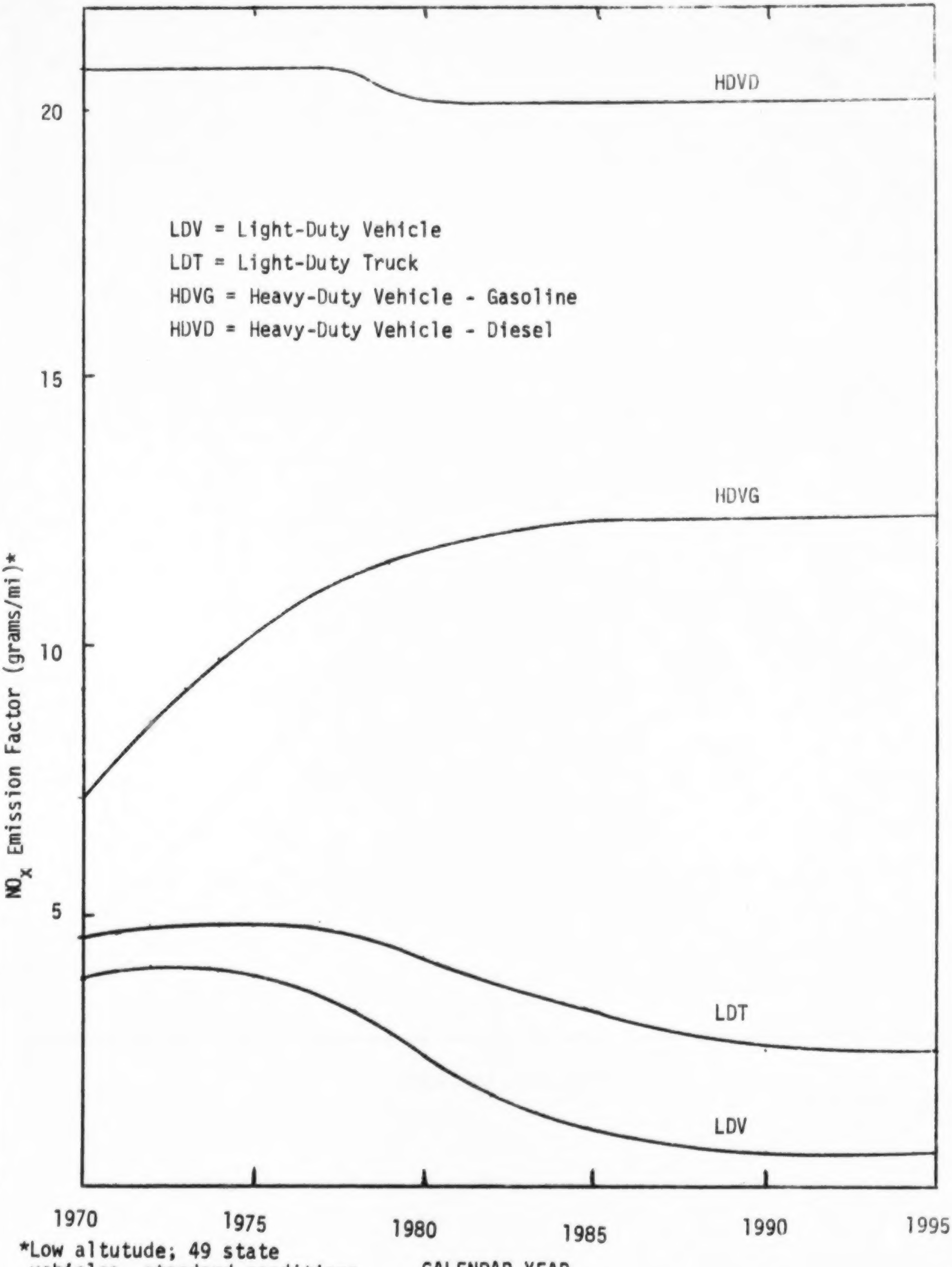
LDV TRAVEL BY MODEL YEAR (m_{in})*



*Based on 1972 Data

FIGURE E-4

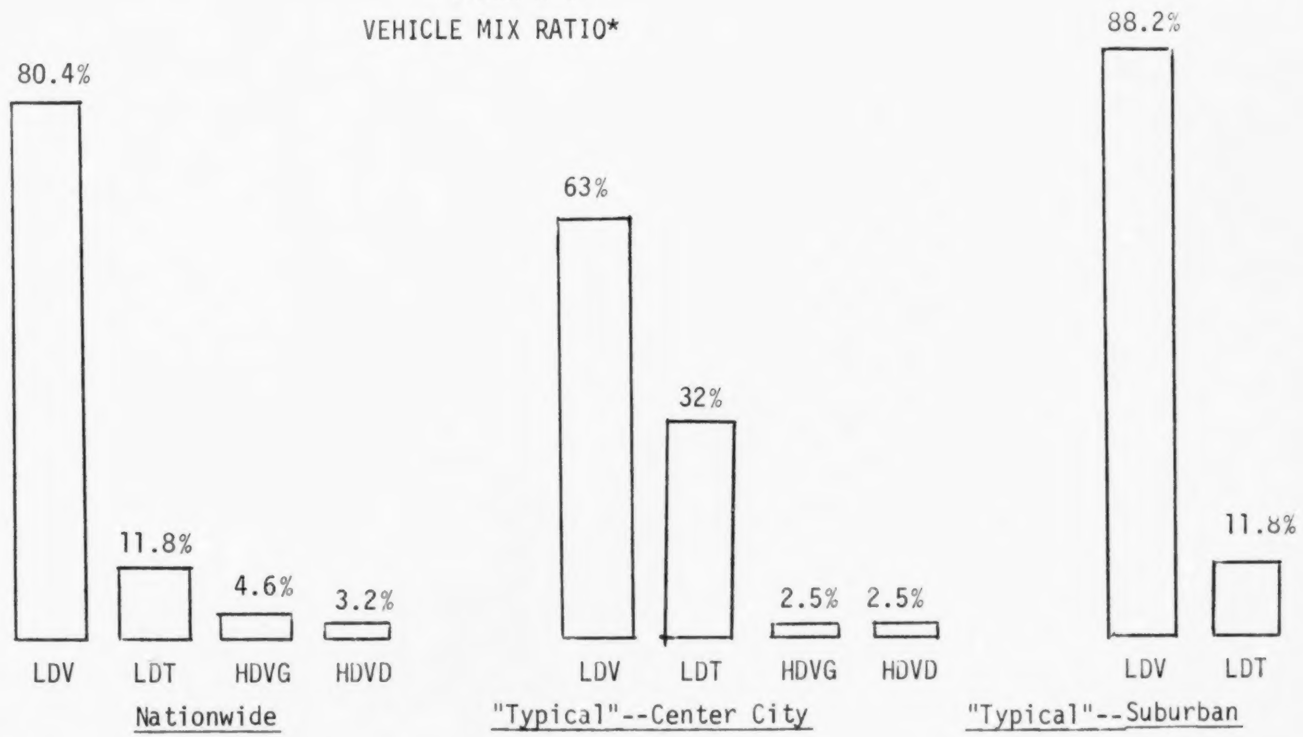
COMPOSITE NO_x EMISSION FACTOR FOR LDV, LDT, HDV, AND HDD VS. CALENDAR YEAR



*Low altutude; 49 state vehicles, standard conditions

FIGURE E-5

VEHICLE MIX RATIO*



*Based on VMT Contribution

FIGURE E-6. NO_x SPEED CORRECTION FACTOR (V_{ips}) FOR LDV

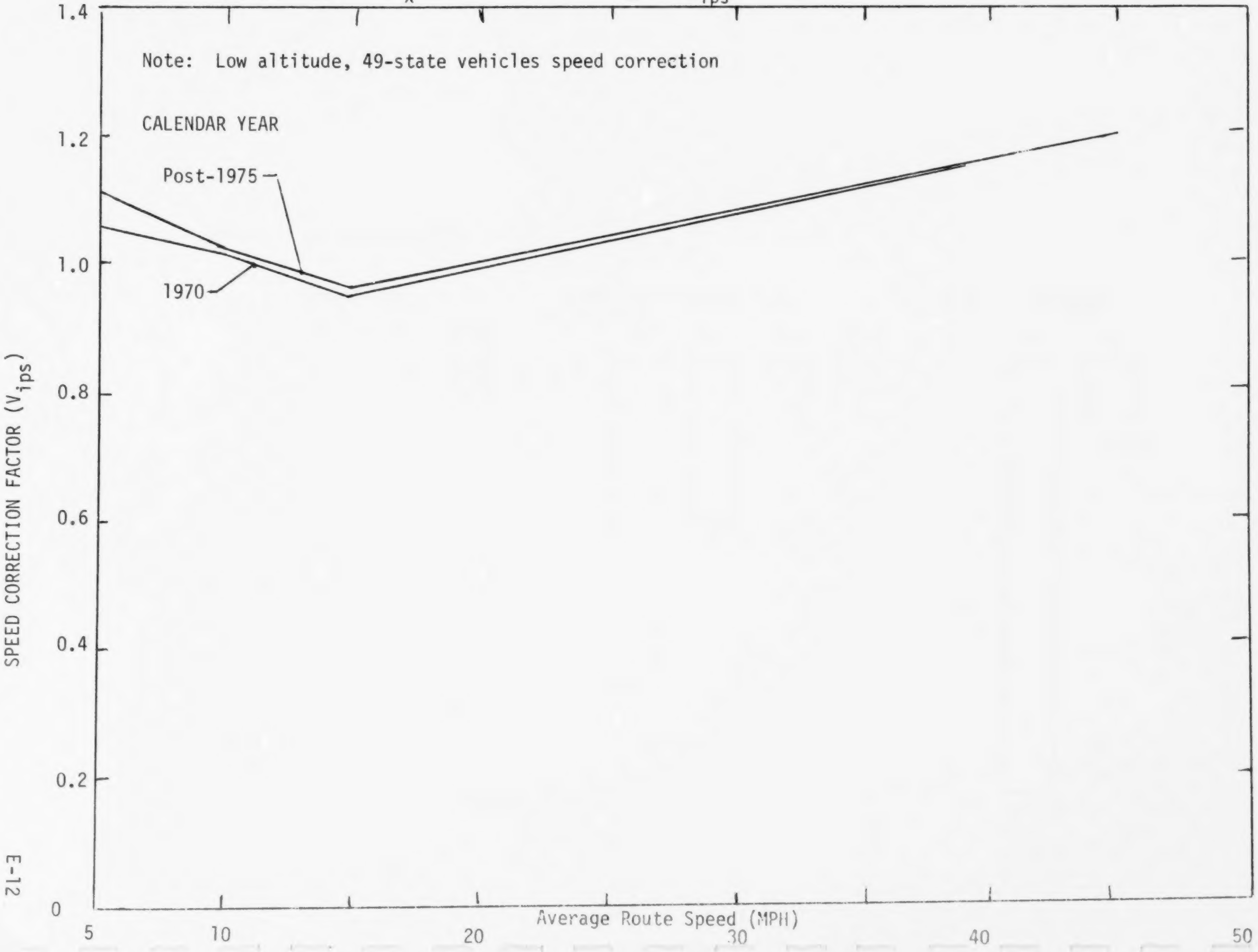


FIGURE E-7. NO$_x$ SPEED CORRECTION FACTOR (V_{ips}) FOR HD

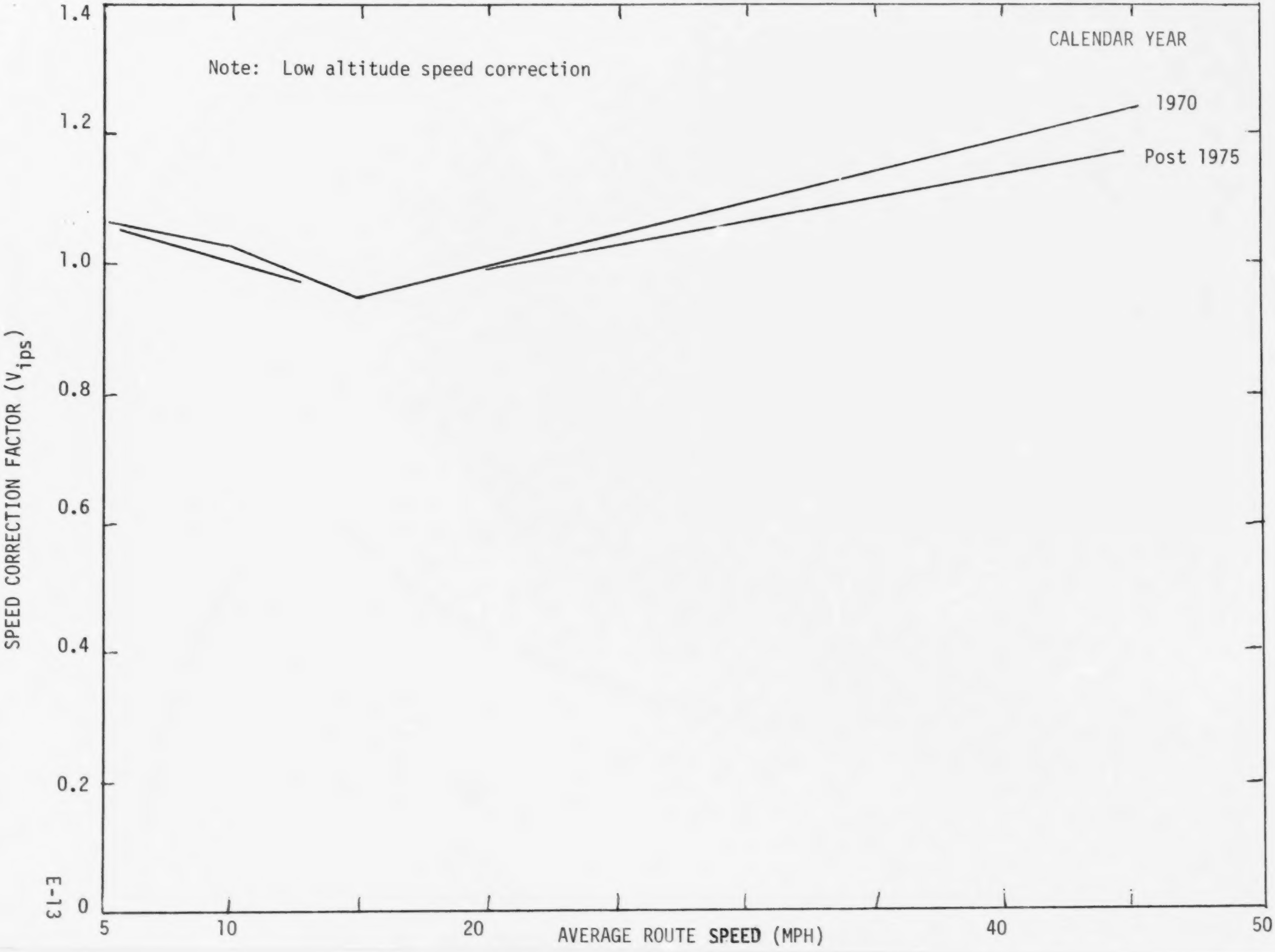


FIGURE E-8. NO_X SPEED CORRECTION FACTOR (V_{ips}) FOR HDVD

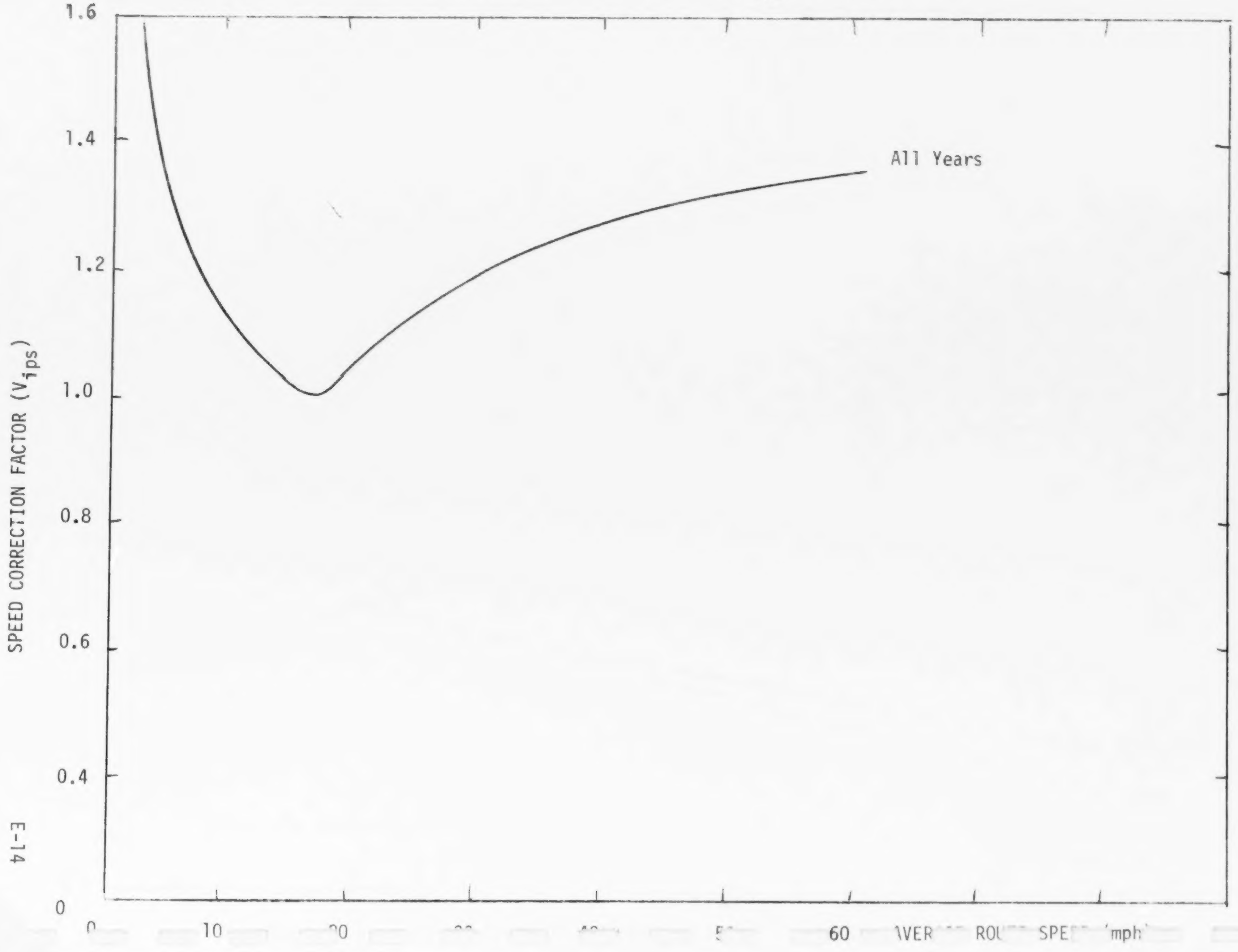


FIGURE E-9. NO_x AMBIENT TEMPERATURE CORRECTION FACTOR (Z_{ipt}) FOR LDV & LDT

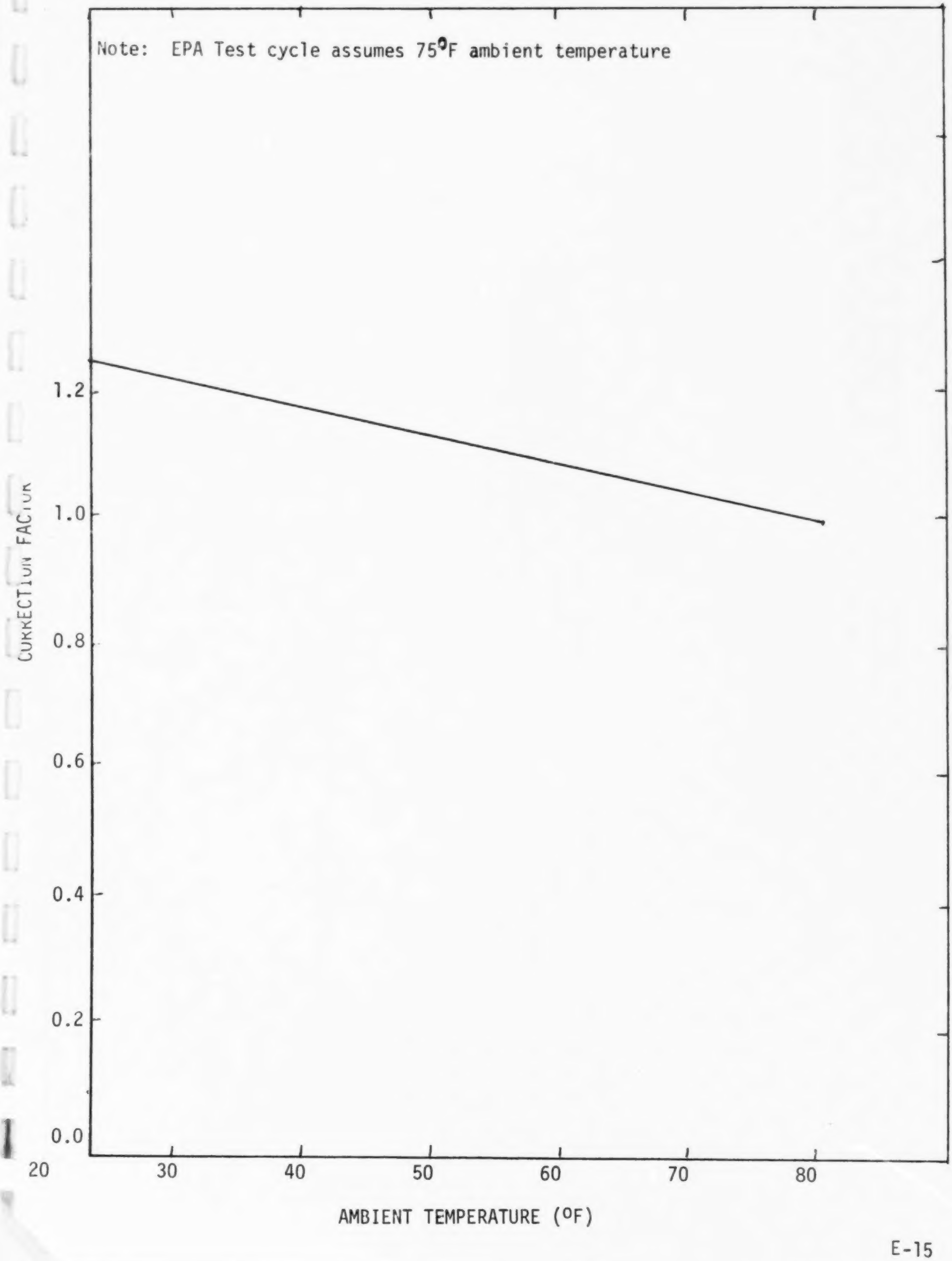
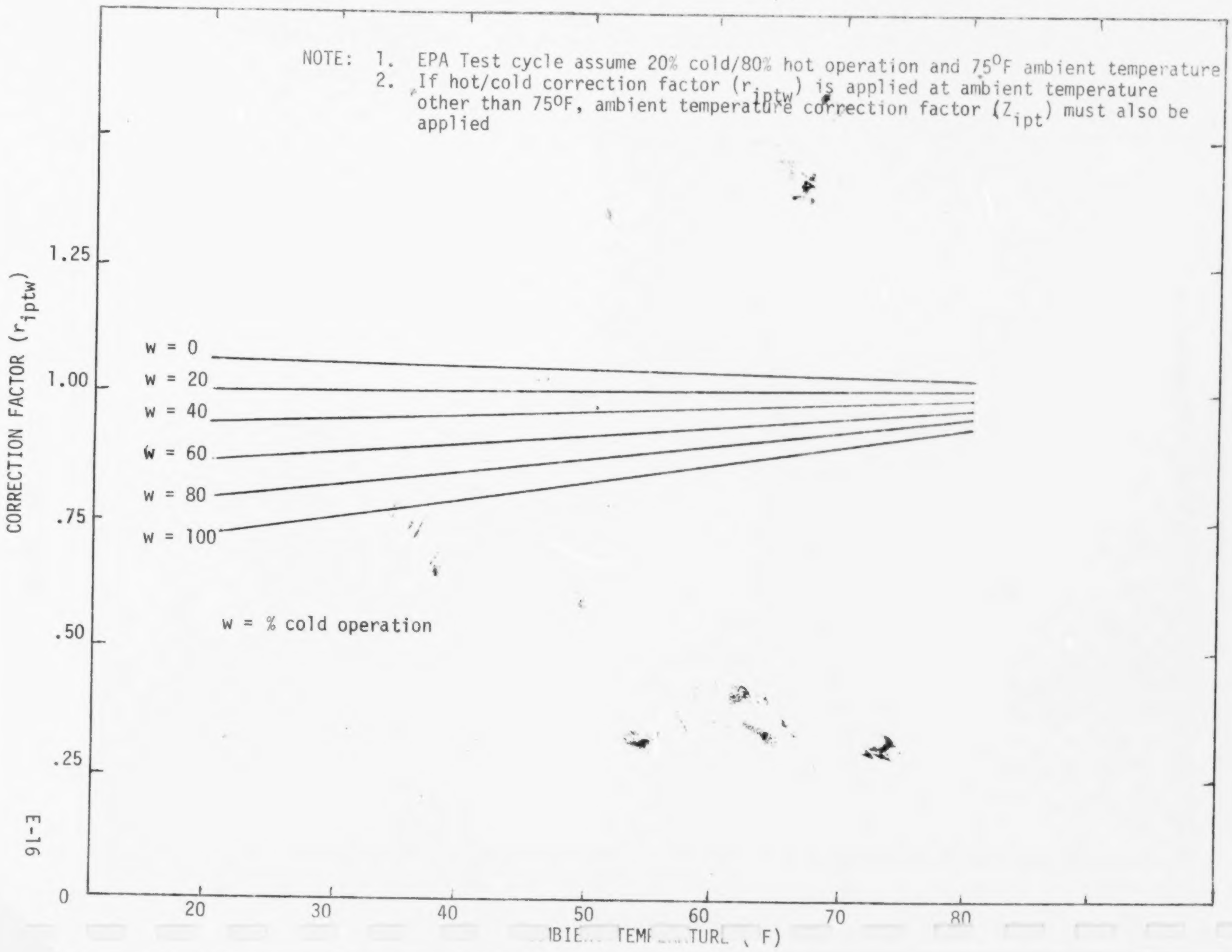


FIGURE E-10. NO_X HOT/COLD OPERATION CORRECTION FACTORS (r_{iptw}) FOR LDV & LDT (NON-CATALYST)



NOTE: 1. EPA Test cycle assume 20% cold/80% hot operation and 75°F ambient temperature
2. If hot/cold correction factor (r_{iptw}) is applied at ambient temperature other than 75°F, ambient temperature correction factor (Z_{ipt}) must also be applied

w = % cold operation

3. Motor Vehicle Emission Standards

Light Duty Vehicles

An NO_x emission limitation for light duty vehicles (LDV) (i.e., any motor vehicle with a gross vehicle weight (GVW)* of 6,000 lbs. or less and used principally for transportation of people) was established by Section 202 of the Clean Air Act (CAA) of 1970 as amended. The Act required EPA to establish regulations that would require 1976 model LDV's to reduce NO_x emissions by 90% of their uncontrolled 1971 emission rate. On July 2, 1971 (at 36 FR 12652) later recodified on November 15, 1972 (at 37 FR 24250) the Administrator established the following emission standards for NO_x emissions:

1973 model year - 3.0 grams per vehicle mile
1974 model year - 3.0 grams per vehicle mile
1975 model year - 3.1 grams per vehicle mile
1976 model year - 0.40 grams per vehicle mile

On July 31, 1973 (at 38 FR 20365) after testimony by automobile manufacturers, control equipment suppliers and the National Academy of Science which had indicated that the statutory standards could not be met by the required attainment date with acceptable reliability, and after the Administrator had determined that full 90% control was not generally needed to attain national standards, except in Los Angeles (June 8, 1973, FR at 15183) the Administrator under the suspension provision of Section 202(b)(5)(D) granted a one-year extension (until 1977) for compliance with the statutory standard to some automobile manufactuers. In conjunction with the extension, the

---

*Total weight of vehicle and maximum load as rated by the manufacturer.

Administrator on July 30, 1973, established a national interim standard of 2.0 grams/mile for 1976 model motor vehicles and postponed the 0.4 grams/mile standard to 1977 model vehicles (August 21, 1973 at FR 22474). At that time it was generally believed the 1976 interim standard was the lowest emission level that LDV could achieve without the use of a reduction catalyst.

In June 1974, the Energy Supply and Environmental Coordination Act (ESECA) modified and postponed these emission rates by legislative decree. Specifically ESECA suspended all automotive emission standards for an additional year; i.e., the NO_x statutory standard of 0.4 grams/mile was postponed to 1978. The 1976 interim standard of 2.0 grams/mile was postponed to 1977 and the 1975 standard of 3.1 grams/mile was maintained for 1976 model vehicles. The present standard (i.e., for 1976 models) is thus 3.1 grams/mile. These standard and proposed changes are summarized in Table E-11.

EPA has recommended to Congress changes in NO_x standards for automotive sources. On March 5, 1975, the Administrator recommended that the NO_x automotive standards be established at 2.0 grams/mile for vehicle models 1977-1982. Final action on automotive emission standards by Congress is anticipated during 1976.

An analysis was conducted by OAQPS which predicted air quality levels in ten cities resulting from eight different emission standards combinations (options). The ten cities (Phoenix; Los Angeles; San Francisco; Denver; New York City; Philadelphia; Washington, D.C.; Chicago; Baltimore; and Salt Lake City) represented the "worst-case" situations (considering air quality and growth) from a list of about thirty urban areas for which 1972 data were available. The analysis indicated that future NO_2

TABLE E-11-SUMMARY OF NO_x LIGHT DUTY VEHICLES STANDARDS

Strategy	Date	NO_x Emission Standards (grams/mile)									
Clean Air Act of 1970, as amended		The law requires EPA to establish regulations that reduce 1971 automotive NO_x emissions by 90% for the 1976 model year.									
		1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
EPA	July 2, 1971	3.1	3.1	3.1	0.4	0.4	0.4	0.4	0.4	0.4	0.4
EPA (1-year Extension)	July 30, 1973	3.1	3.1	3.1	2.0	0.4	0.4	0.4	0.4	0.4	0.4
ESECA*	June, 1974	3.1	3.1	3.1	3.1	2.0	0.4	0.4	0.4	0.4	0.4
Proposed Amendments											
President	June 27, 1975	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	a
EPA	March 5, 1975	3.1	3.1	3.1	3.1	2.0	2.0	2.0	2.0	2.0	2.0
U. S. House of Representatives U. S. Senate	Various automotive emission standards are being studied by Congress.										

*Currently in effect

[a] After 1982 standard would be determined by Administrator

levels will exceed the air quality standards in most of the ten cities under all eight of the automotive control options, primarily because of the growth of stationary sources which will constitute the major contribution of NO_x emissions. Variations in the control of automotive exhaust do, however, make differences in NO_2 levels in each of the ten cities studied by affecting the rate the NO_2 air quality level deteriorated. Under the strictest option (i.e., 0.4 gram/mile), an average increase in ambient NO_x concentrations of 6 percent by 1980 would be experienced in the 10 cities examined, and under the most lenient option (i.e., 3.1 gram/mile), the average increase would be 16 percent by 1980.

Light Duty Trucks (LDT - gasoline powered)

Uncontrolled NO_x emissions from gasoline powered LDT's range between 1.6 to 5.3 grams/mile, depending upon age of the vehicle and whether the vehicle is operated at low or high altitude. Presently the LDT standard is identical to the LDV standard; i.e., an emission limitation of 3.1 grams/mile beginning with model year 1975.

An NO_x emission standard of 2.3 grams/mile beginning in 1978 for light duty trucks was proposed in the Federal Register in February 1976. The proposal will also change the distinction between light and heavy duty trucks from the present 6,000 lbs GVW to 8,500 lbs. GVW. This proposed LDT standard is significantly below the uncontrolled emission rate of NO_x, which was approximately 3.5 grams/mile in 1967 prior to the introduction of HC and CO controls and which caused the average NO_x emission rate to increase to 5.3 grams/mile in 1973.

Heavy Duty Trucks (HDT)

Uncontrolled NO_x emissions from gasoline-powered HDT range from 4.1 to 12.6 grams/mile depending upon the age of the vehicle and whether the vehicle is operated at high or low altitude. Additionally, the NO_x emission rate from diesel powered HDT is approximately 21 grams/mile. The current standard in effect (see November 15, 1972 FR at 24287) is combined HC and NO_x emission limitation of 16 grams/brake horsepower hour. This standard applies to vehicles of model years 1974 through 1977. In addition, a combined standard for hydrocarbon and NO_x of 10 grams per brake horsepower hour beginning with 1979 model vehicles was proposed for heavy duty trucks in the May 24, 1976, Federal Register. This standard is approximately equal to a standard of 9 grams per brake horsepower hour for NO_x.

SECTION F

TRANSPORTATION CONTROL PLANS

The need to reduce automotive emissions in some areas below the levels resulting from Federal Motor Vehicle Control Program (FMVCP) was specifically recognized in the Clean Air Act. After review of the SIP's, EPA required certain states to submit plans containing various transportation control measures to reduce automotive emissions in 27 Air Quality Control Regions. On June 8, 1973, the Administrator promulgated regulations to amend 40 CFR, Part 51, to clarify the requirements for transportation control strategies.

Transportation control measures included in SIP's are of two basic types; i.e., measures that reduce emissions from individual vehicles and measures that reduce general automobile use (vehicle-miles-traveled or VMT). The first type of control measure includes inspection/maintenance and retrofit programs. The second type includes transit improvements, carpool programs, disincentives to the use of low-occupancy automobiles and parking restrictions.

Impact of Various Transportation Control Measures on NOx Emissions

The principal thrust of transportation measures to date has been aimed at reducing levels of carbon monoxide (CO) and photochemical oxidants (Ox). In some cases those actions result in concomitant increases or decreases in NOx emissions.

Auto-used and emissions reductions achieved by transportation controls derive from the effects of the entire group of measures included in a transportation control plan, rather than the effects of individual measures. Moreover, the effectiveness of specific auto-used reduction approaches is strongly dependent on local conditions. Hence, in any consideration of NOx reductions identified with specific control measures, it is necessary to view these reductions as rough estimates which are subject to change when placed in the operating framework of the entire TCP for a particular area.

(a) Non-VMT measures.

Several control measures are available to reduce emissions from individual vehicles. Since these control measures require that individual vehicle emissions be reduced by a certain amount, it is relatively easy (when compared to VMT reductions) to quantify emission reductions that may result from the implementation of these control measures.

Inspection and Maintenance

Inspection and maintenance (I/M) programs, which provide for inspection at least once a year to primarily check HC and CO emission rates of motor vehicles, do not significantly affect NOx emissions. Analyses of two studies by Olson Laboratories showed that I/M increased annual emissions of NOx by 0.8 and 1.4 percent respectively. Neither of these increases was statistically significant, even though fleet sizes were larger (600 and 144 vehicles). These negligible increases in NOx levels are due principally to increased temperatures accompanying improved combustion efficiency.

Retrofit

Retrofit means the addition or removal of an item of equipment, or a required adjustment, connection, or disconnection of an existing item of equipment, on an in-use vehicle for the purpose of reducing emissions. Retrofit devices can be used singly or in combination with other retrofits to optimize control of NOx, HC and CO emissions for both light duty and heavy duty vehicles. Studies on both light and heavy duty vehicles have demonstrated the potential for retrofit devices to be very effective in reducing NOx emissions, all of which are contained in the exhaust gases.

NOx retrofits can be used on both controlled (1968-1974) and on pre-1968 uncontrolled vehicles. Of the two approaches currently certified for use in California, one uses exhaust gas recirculation (EGR) plus vacuum spark advance disconnect (VSAD) and the other uses only VSAD. The NOx control devices used for the California retrofit program for 1966-1970 vehicles were designed to reduce NOx emissions by at least 40 percent without increasing HC or CO emissions.

The central technical problem in controlling NOx emissions by retrofit is to optimize the choice among various combinations of retrofit devices considering the pollutant problems at hand. Another major variable affecting the optimization of retrofit devices is altitude. Studies in Denver, Colorado, have shown additional reduction in NOx emissions from retrofit at high altitude although simultaneously increasing HC and CO emissions. The choice of retrofit options is thus a delicate balance among the three pollutants, the feasible technical approaches, and the estimated use of the vehicle.

Additionally, the California retrofit problem encountered stiff public opposition. Therefore, a light duty vehicle retrofit program must be viewed as one of the lesser politically feasible measures.

VMT Measures

VMT reduction measures most frequently found in TCP's approved or promulgated by EPA include: transit improvements, carpooling programs, priority treatment for buses and carpools on streets and freeways (e.g., exclusive bus lanes), and parking restrictions. These interrelated measures reduce VMT, hence reduce the amount of fuel burned and consequently the amount of NOx emissions.

The maximum emission reductions from transportation measures will result from coordinated measures designed to discourage low occupancy auto use and to encourage transit and carpool use. However, transit and carpool incentives by themselves are insufficient for achieving significant emission reductions. Programs that do not incorporate parking restrictions, surcharges, or other disincentives are unlikely to achieve emission reductions greater than 5 to 10 percent. For further information on specific measures refer to the attached list of reference materials.

References/Bibliography

1. A Review of Control Strategies for In-Use Vehicles, EPA, December 1974, EPA-460/3-74-021

2. Applications for Accreditation of NOx Control Devices, State of California, Air Resources Board (undated)

3. Transportation Controls to Reduce Automobile Use and Improve Air Quality in Cities, EPA, November 1974, EPA-400/11-74-002

4. An Evaluation of Retrofit Devices for Heavy Duty Vehicles, (Draft), New York City Department of Air Resources, December 1975

5. Effectiveness of Short Emission Inspection Tests in Reducing Emissions through Maintenance, Olson Laboratories for EPA, July 1973, EPA-460/3-73-009

6. Degradation Effects on Motor Vehicle Exhaust Emissions, (Draft), Olson laboratories for California Air Resources Board, 1976

SECTION G

FIELD OBSERVATIONS

Recently a study of short-term NO_x concentration distributions over urban/suburban areas was conducted. A review of available air quality data indicated that only St. Louis (25 sites) and Los Angeles (24 sites) had sufficient data for analyzing the spatial character of NO_2. Three days of hourly data were analyzed for each city with days of relatively high NO_x concentrations selected for analysis.

A review of the 24-hour NO_2 concentrations in St. Louis indicated that the highest NO_2 concentrations were recorded in an area along the prevailing wind direction and slightly downwind of the major industries clustered near the center of the city. On each day, the concentrations would rapidly decrease with increasing downwind distance such that suburban NO_2 concentrations at 25 miles downwind were only one-fourth to one-half of the city center value. (See Figures G-1, G-2, and G-3.)

In Los Angeles the 24-hour NO_2 concentrations patterns were more complex than in St. Louis. It is expected that the day/night land/sea airflow patterns and complicating topographical features in the Los Angeles Basin tend to channel and inhibit surface air flow and result in complex wind flow patterns. For the days analyzed similar concentration patterns were observed. On each day there appeared to be four different areas of high NO_2 concentrations with all four maxima located downwind of the Los Angeles city center. The 24-hour NO_2 concentrations in the basin dropped rapidly with increasing downwind distance with an approximate gradient of 20 $\mu g/m^3$ (0.01 ppm) per mile. The analysis also indicated that NO_2 concentrations in Los Angeles may be twice as high in the fall and winter as in the spring and summer.

A review of the 1-hour NO_2 data for St. Louis indicated that peak 1-hour NO_2 concentrations also occurred downwind of major city sources from 8:00 p.m. to 10:00 p.m. on 2 days and 4:00 a.m. to 8:00 a.m. at the center city sites on the third day. (See Figure G-4.) The general urban area (excluding the center city) reached its maximum concentration at 10:00 p.m. on the third day. In Los Angeles maximum 1-hour concentrations occurred during the mid-morning to noontime along the coast and center city, but during the evening in suburban and inland sites.

In summary, the analysis indicated that high short-term NO_2 concentrations tend to occur in and immediately downwind of the city center and decrease rapidly with distance outward toward rural areas. These findings imply that the maximum annual NO_2 concentrations in an urban area would be expected to occur slightly downwind of the center city industrial complex along the most persistent wind directions.

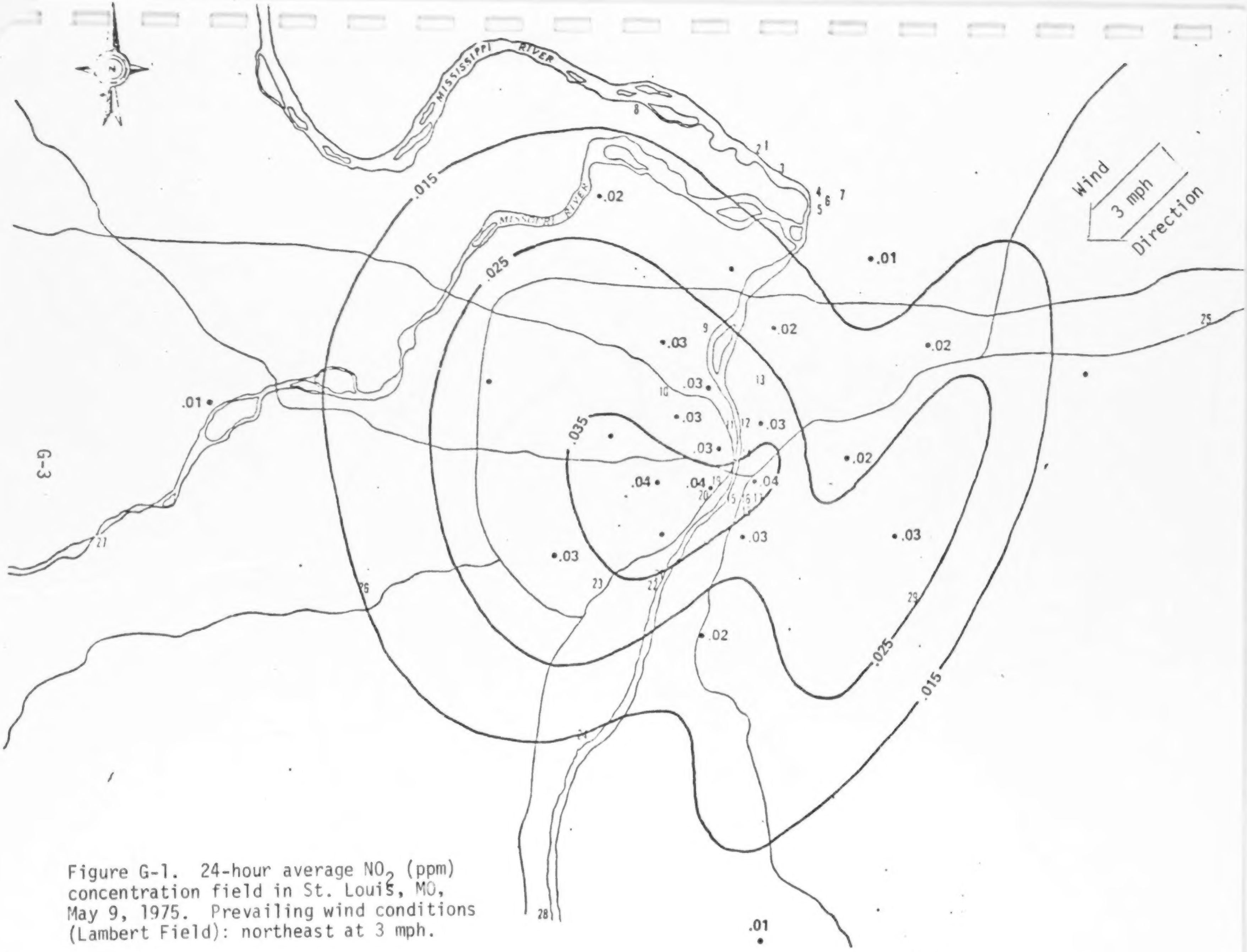

MISSISSIPPI RIVER
MISSOURI RIVER
Wind
3 mph
Direction
.015
.025
.035
.025
.015
.01
.02
.01
.03
.02
.02
.03
.03
.03
.03
.02
.04
.04
.04
.03
.03
.03
.02
.01
1
2
3
4
5
6
7
8
9
10
11
12
13
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29

Figure G-1. 24-hour average NO_2 (ppm) concentration field in St. Louis, MO, May 9, 1975. Prevailing wind conditions (Lambert Field): northeast at 3 mph.

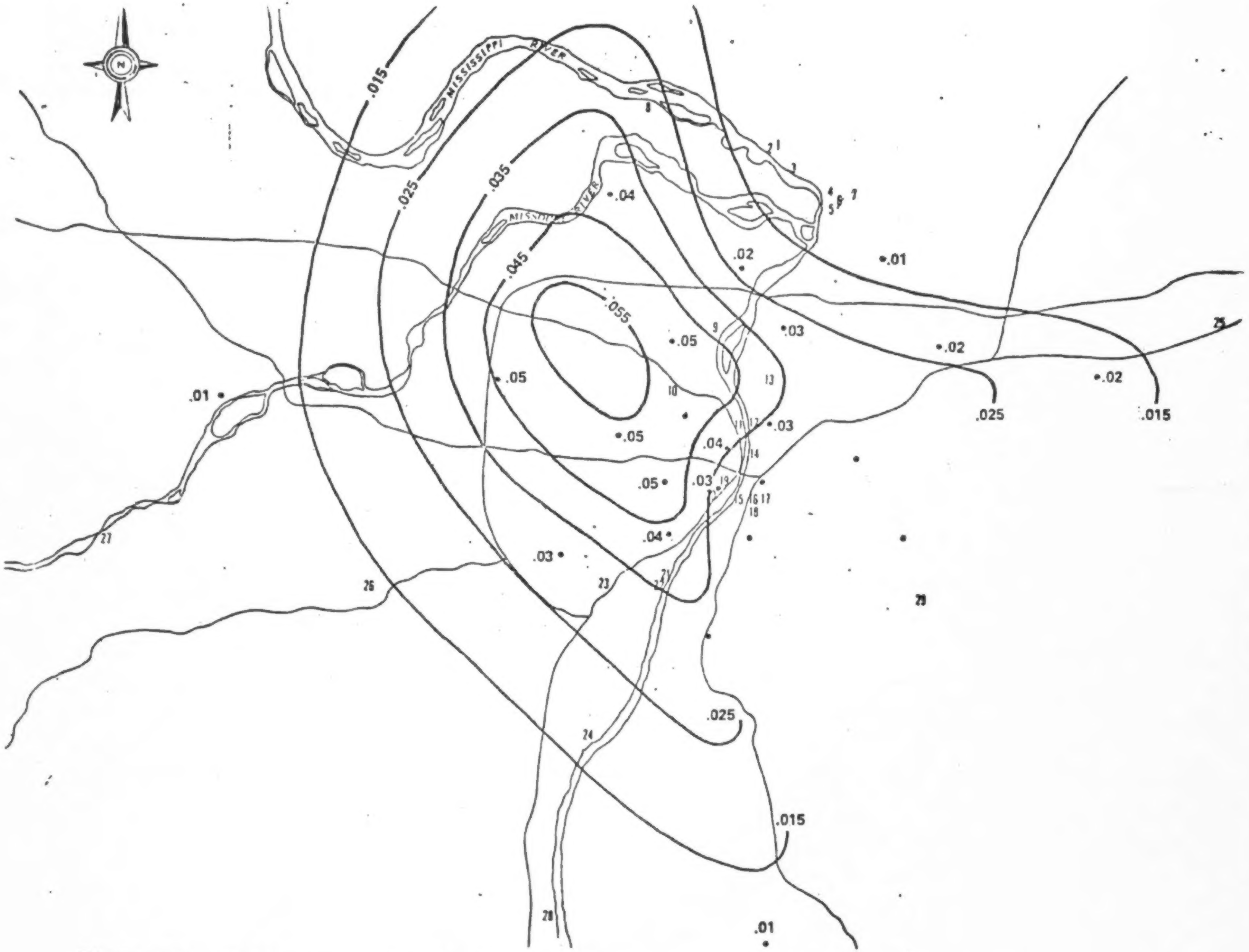

MISSISSIPPI RIVER
MISSOURI RIVER
.015
.025
.035
.045
.055
.04
.02
.01
.03
.05
.05
.05
.05
.04
.03
.04
.03
.01
.02
.02
.025
.015
.025
.015
.01

Figure G-2. 24-hour average NO_2 (ppm) concentration field in St. Louis, MO, May 17, 1975. Prevailing wind conditions (Lambert Field): light and variable.

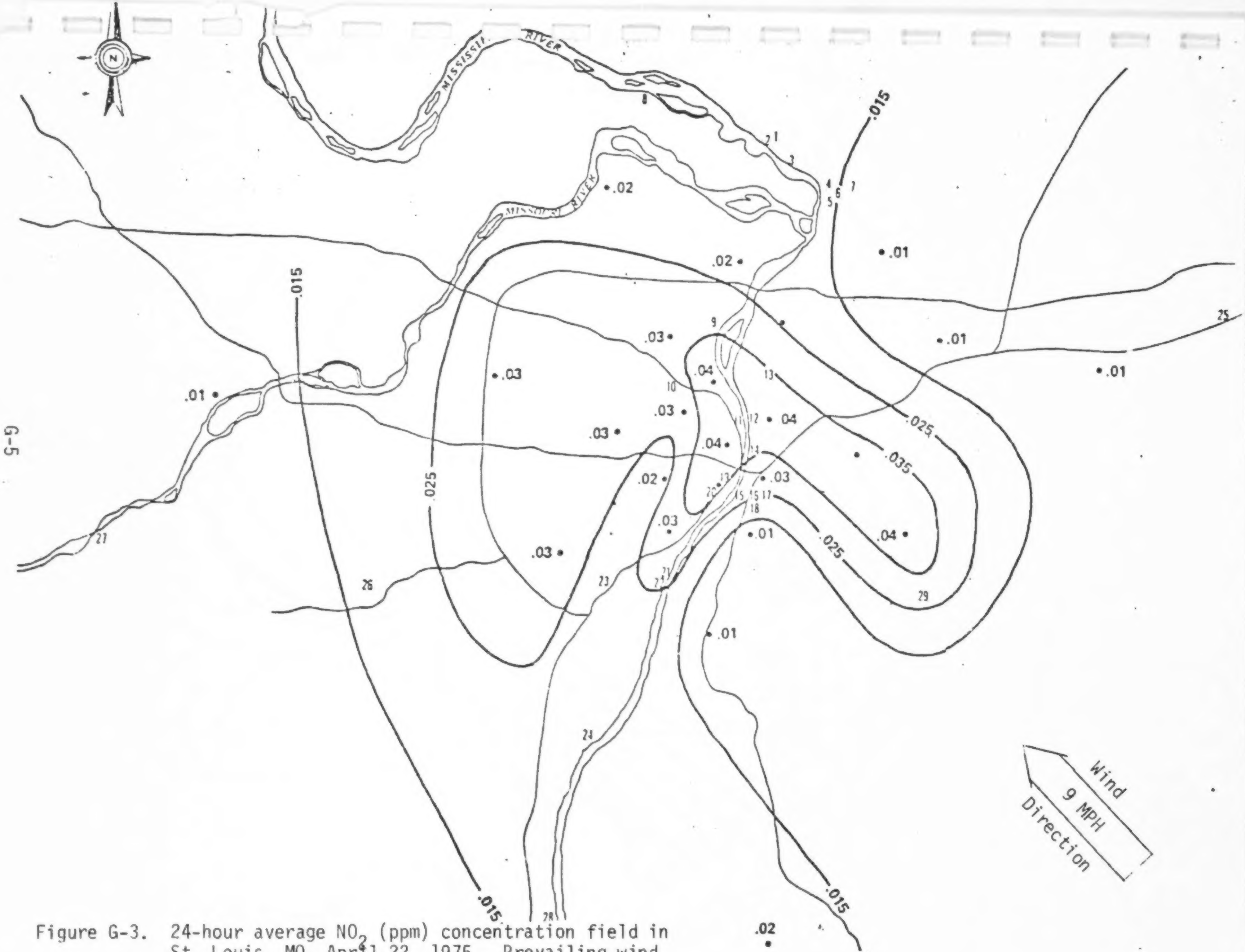

MISSISSIPPI RIVER
MISSOURI RIVER
N
Wind
9 MPH
Direction
.015
.025
.035
.04
.03
.02
.01

Figure G-3. 24-hour average NO_2 (ppm) concentration field in St. Louis, MO, April 22, 1975. Prevailing wind conditions (Lambert Field): southeast at 9 mph.

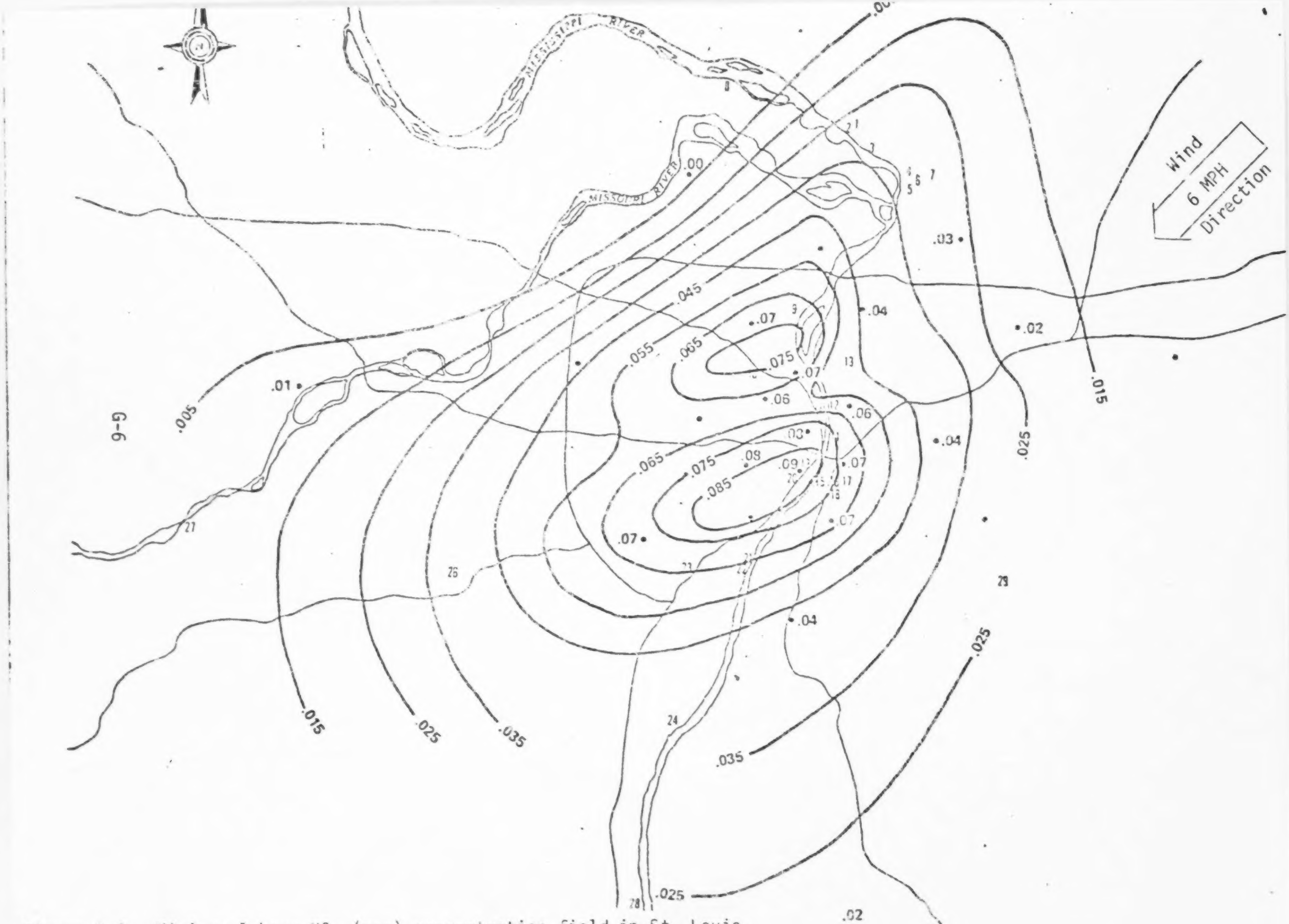

MISSISSIPPI RIVER
MISSOURI RIVER
Wind
6 MPH
Direction
.005
.01
.015
.025
.035
.045
.055
.065
.075
.085
.00
.02
.03
.04
.06
.07
.08
.09

Figure G-4. Minimum 1-hour NO_2 (ppm) concentration field in St. Louis, MO, 2200 CST, May 9, 1975. Meteorological conditions (Lambert Field): Winds: northeast at 6 mph, temperature: 65°F.